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Notices of the Royal Aëronautical Society.

Elections, July 15th, 1919.

Hon. Fellow.—Major B. F. S. Baden-Powell.

Associate Fellows.—Major G. H. Abell, R.A.F., H. J. Alpe, W. Kennedy Boyne, W. Bryson, W. C. Gardiner, A. V. C. Lima, W. H. Lyne, N. Meadowcroft, B. Paterson, Captain H. King Paton, R.A.F., Sydney Pickles, Captain L. F. Plugge, Major F. D. Rennie, F. L. Richards, Captain F. M. Rope.

Members.—C. F. T. Walker, Paul Shishkoff.

Students.—Bernard Arnold, S. F. Bickle, G. E. Gardner, V. J. Johnston, E. Lethbridge, P. H. Linton, D. Murray, W. J. Pickhorn, J. D. Williams.

Associate Members.—Miss A. D. Betts, C. J. H. Knight.

Foreign Members.—G. E. Moreton, H. V. W. Wheeler.

The Glossary of Aeronautical Terms

Prepared by the Technical Terms Committee of this Society, as approved by the Engineering Standards Association, and including the agreed system of aerodynamical symbols prepared after consultation with the Advisory Committee for Aeronautics, is now ready and can be obtained from this office, price 2s. 6d., post free 2s. 9d.

Obituary.

Mr. A. S. A. Ormsby was the second son of J. D. Ormsby, Esq., of Lime Hall, Jamaica, W.I.; he was educated in Jamaica, and afterwards apprenticed to the firm of Mirlees, Watson and Co., engineers, Glasgow. He completed his scientific education at Anderson's College, Glasgow, and was awarded a Whitworth Scholarship. He also gained a National Scholarship under the Science and Art Department, tenable for three years at the Royal College of Science, in 1883, but soon resigned this on being appointed Assistant Examiner at H.M. Patent Office, where he rose to the rank of Senior Examiner. In 1912 he was awarded the degree of LL.B. at the University of London, and was attached to the Ministry of Munitions (Inventions Department) for the greater part of the period of the war. He rose to the position of Director in this department.

LORD RAYLEIGH.

The death of Lord Rayleigh has removed one of the pre-eminent figures in the history of British science, one who stands with Kelvin, Stokes, Clerk Maxwell in the front rank of those great mathematical physicists whose achievements and teaching have had so profound an effect on the advancement of science, in practice as well as in theory, during the last half-century.

He had all the attributes which go to make the great discoverer in natural philosophy, imagination, intense interest in all the problems this world presents, experimental ability, mathematical skill, combined with clear reasoning power and the faculty of lucid exposition. His range was of the widest, and in almost every subject he touched he was a specialist. He was the great authority on sound problems, the foremost writer on optics, joint discoverer of argon, a discovery which was the outcome of his accurate work in the redetermination of the densities of the principal gaseous elements; he made important contributions to electrical theory and carried out one of the earliest determinations of high accuracy of the fundamental electrical units; he added to our knowledge of hydrodynamics of tidal theory, of thermodynamics and the dynamical theory of gases.

His connection with aeronautics has been a long one and his contributions to aeronautical science are perhaps still not so well known as they deserve to be. He was already interesting himself in the subject and conducting valuable experiments in relation to it at a time when very few scientists of eminence found it worthy of attention. In 1876 he developed in a paper published in the "Philosophical Magazine" the theory of the inclined plane. In 1883 he was writing on the soaring of birds. A review in "Nature" in 1891 of Langley's "Experiments in Aerodynamics" shows how familiar he was already with the fundamental problems of the subject, and indicates, too, the attention he had paid to the work of earlier writers such as Wenham and Pénaud. His lecture in 1900 to the Manchester Literary and Philosophic Society on the Mechanical Principles of Flight shows, as does all his work, the clearest understanding of fundamental principles and contains much that is of permanent value to the student of aerodynamics. In this paper he takes up again the question of soaring flight, from which he passes to a general discussion of the motion of an aeroplane, whether power-driven, or gliding under gravity. He considers the action of an airscrew and the possibility of direct maintenance in the air by a screw rotating about a vertical axis, and while pointing to the advantages of the direct lift machine he remarks that "the flying machine of the future will, as it appears to me, be on the principle of the aeroplane." A brief theory of flight by wing flapping is also given.

When the Advisory Committee for Aeronautics was appointed by the then Prime Minister, Mr. Asquith, in 1909 he was fitly nominated as President, and until within a few weeks of his death, he continued, with rare absences, to preside over its discussions and to take a keen interest in every advance in aerodynamical theory and practice. His note, included among the papers published in the first annual report of the Committee, on the application of the principle of dynamical similarity in aerodynamics, a principle to which Lanchester had also drawn attention, set out in a convenient form a fundamental condition governing the use of models for the determination of data required for aircraft design, which has been of the greatest utility in the correlation and simplification of experimental results. Throughout all the investigations of the Committee, this clear grasp of fundamental principles which was so strong a characteristic of his own researches, has been of great assistance in securing that the work should proceed on a sure basis.

He was an Honorary Fellow of the Society and his name adds distinction to the roll of Fellows, which already includes many names which will keep an enduring place in the history of aeronautics. His life and work will be for all time an example and an inspiration.

SOME POINTS IN AEROPLANE DESIGN.

BY CAPTAIN F. S. BARNWELL, R.A.F.

It is quite impossible in the scope of a single paper to deal with more than a small part of the vast subject of aeroplane design. What I have attempted, therefore, is to work out a few points which seem worthy of particular attention, and thence to suggest what would appear to be the best practice.

It is probable that what I have done has been done already by most people who have been engaged on designing work for the last few years, and probably done more fully and more accurately. But it has entailed quite a fair amount of work, and the results have been of some interest and value to myself, so I hope that they may prove the same to others.

I shall try to make quite clear the data from which I start, the assumptions I make and the limitations of the conclusions arrived at, so I trust that nothing should be misleading even if it be more or less incorrect. To those of you who have not done very much the same work for yourselves I hope that it may be of some value, whilst to those of you who have, I hope that it may be of interest as corroborating or contradicting your own conclusions. It is perhaps unnecessary to state that I have not consciously plagiarised, so that anything given in this paper may at any rate be regarded as an independent check.

The first subject touched upon is the aerofoil (Plate 1). It is a debatable question whether any one form of aerofoil section can be taken as the best for all types of aeroplane. Generally speaking, the thicker the section the lighter will be the main spars for the same strength, but the worse the optimum lift over drag and the worse the lift over drag at small values of lift. Moreover, in a thick section the maximum lift value is not much higher than in a thinner one and the critical angle tends to occur earlier. Taking it all round, I believe that little is to be gained by using different forms of section, and that it will nearly always prove advantageous to use a so-called "high speed" form of section and to vary the loading and points of support so as to suit best any particular case.

I show an aerofoil section here which is quite a good standard. I do not wish to infer that it is the "best" form, but it is not a bad one and will serve as a jumping-off point. It is, actually, a mean between two sections for which I have experimental data. I have assumed, therefore, that its aerodynamic properties are the means; this is probably rather inaccurate, but I escape the accusation of giving away actual data. I shall allude to it henceforth as "standard section."

The next point to consider is the plan form, which includes the question of aspect ratio and of shape of ends. In any aerofoil structure other than a cantilever, I do not think there is any noticeable advantage in tapering from root to tip. There is a distinct aerodynamic gain in rounding off and fining down the tips, but there is little more to be gained by rounding them off more than is shown in this figure. This form of end is what I think, at present, to be the right type. It gives, I think, more efficient aileron control, by which I mean better rolling moment for the same force applied by the pilot than does the "raking" tip which we have nearly all used for some years past; it is probably as aerodynamically efficient a form as any other of the same length of taper, and it gives front and rear spars of approximately the same length, which is an advantage from the weight for strength point of view.

I shall call this the "standard" wing tip. For purposes of getting out areas there is shown in dotted lines, the end of the rectangle which is of same chord and of same area as the aerofoil; (area/chord) + $\frac{1}{4}$ chord gives us the necessary extreme span for an aerofoil with these "standard" tips. The span of this rectangle is

the " mean " span for the aerofoil, and the aspect ratio of the rectangle the " mean aspect ratio " of the aerofoil.

Now to consider the aerodynamic properties of this aerofoil of " standard " section and with " standard " tips.

The family of curves shown here are all for values of lift/drag on a base of " absolute " lift coefficient.

Curve (1) is for a model size aerofoil of 6/1 aspect ratio, of rectangular plan form, of " standard " section and of 3in. chord, at a wind speed of 40 feet per sec. It is actually run from the mean values of wind tunnel figures for two models, and probably represents facts fairly accurately.

Curve (2), however, is a result of wild exterpolation and guessing; it purposes to be that for a full size aerofoil (say over 3ft. chord) of 5/1 " mean " aspect ratio, of " standard " section and with " standard " ends at full size speeds (say over 40 m.p.h.). I do not guarantee that it is even approximately accurate, but I *think* it is round about it.

Curve (3) is for monoplane form of " mean " aspect ratio 7. Curves (4), (5) and (6) are for biplane forms of " mean " aspect ratios 5, 7 and 9 respectively, whilst curves (7), (8), (9) and (10) are for triplane forms of " mean " aspect ratios 5, 7, 9 and 11 respectively. All of curves (2) to (10), inclusive, are for " full size " aerofoils of " standard " section, with " standard " tips, at " full size " speeds. For the biplane and triplane forms the " mean " aspect ratio is that of each aerofoil, of course. In all cases the gap is equal to eight-tenths of the chord, and there is no stagger.

To obtain these curves I have used figures from model experiments, assuming that relative values are the same for full size monoplane, biplane and triplane as they are for model. Similarly, for increasing aspect ratio, I have taken that the effect is in the same proportion for full size monoplane, biplane and triplane as it is for model *monoplane*.

So it is quite probable that these curves are far from the truth. I propose, however, now that I have explained their manufacture, to use them later on for comparing different types of full size aeroplanes.

I have attempted next an investigation into the optimum position for the main spars of an aerofoil. I have assumed the usual practice of two spars only, though there is an interesting field for further investigation as to whether it might not be of advantage to use a greater number. For a very highly loaded aerofoil it might prove economical to employ more than two spars instead of increasing the number of points of support.

I assume that the spars are solid spruce of I section, and that the section is of the proportions here given. It is doubtful, but again a subject for further investigation, whether there be any other form of cross section more economical than the I; anyhow, the spindling of an I section cannot be made appreciably greater than that shown here without fear of weakness in shear along the neutral lamination. (Plate 2.)

The maximum depth of spar is governed by the aerofoil section, it is taken hereafter as equal to thickness of section on vertical centre line of spar, minus one tenth of maximum thickness of section, to allow for thickness of flanges of ribs. I have worked out tables of " spar values," each table being for one position of front spar and for six different positions of rear spar. One sample table is shown here, that in which front spar centre is at .1 of chord length from leading edge, and rear spar centre is taken at .5, .54, .58, .62, .66 and .7 of chord length from leading edge, in turn.

The methods used in getting out these tables are as follows:—Centre of pressure taken as at .28 for load on front spar, and as at .6 for load on rear spar; " factor of safety " for rear spar taken as .75 that for front. Calling the depth of spar at .14 chord from L.E. unity, the section value, or " figure of merit," for a spar at any other point is taken as of amount $(2d^4 + d^2) \div 3$, where d is the depth of spar expressed as a fraction of depth of spar at .14. The reason for

this value, which is certainly open to criticism, is that for a constant form of spar section the moment of inertia varies as the fourth power of the depth and the sectional area as the square, and I have assumed that normally about two-thirds of the stress applied to the spar is due to bending and one-third to direct compression.

In the left hand space of the table then we have the "figure of merit" for the front spar, at its fixed position for this particular table.

Column (1) gives position of centre of rear spar, column (2) gives depth of rear spar (as fraction of depth of spar at .14 of course), column (3) gives values for square of rear spar depth, column (4) gives values for fourth power of rear spar depth, and column (5) gives "figure of merit" for rear spar. Column (6) gives value for load on front spar when C.P. is at .28, expressed as a fraction of total load on both spars. Column (7) gives load value divided by "figure of merit" value for front spar, and this is called "required moment of inertia value." We turn to the curves of value for standard I cross section and find where this "required moment of inertia value," set up vertically to scale, touches the curve of "values for *Iv*." Dropping a vertical to the base line from this point, we get firstly a reading on the base line for b/d value required for cross section, which value is set down in column (9); secondly, we measure to scale the value of cross sectional area on the "values for A" curve, which value is put down in column (8) and called "corresponding value on A curve." Column (10) gives a value for front spar weight, obtained by multiplying this "corresponding value on A curve" by d^2 value for front spar (*i.e.*, .85 for this table), and dividing by an empirical constant .6325. This empirical constant comes in because I have assumed that with front spar at .14 and the rear spar at .5, the weight of the front spar shall be taken as unity, and its breadth as one half of its depth. Columns (11) to (15) give similarly obtained values for rear spar, the only difference being of course that the spar "figure of merit" is different for each line and is taken from column (5). Column (16) is the sum of values in columns (10) and (15) and is value for weight of both front and rear spars.

I am afraid that the methods are not explained particularly clearly, and that they are not as accurate as might be desired, but further space cannot be afforded to them.

(Plate 3.) Here are given curves for weights of front spar, rear spar, and sum of front and rear spars on a base of position of rear spar. The values plotted are those found by the methods just outlined.

It is interesting to note some of the points which these curves bring out.

Front spar is throughout lighter than rear, it is nearly as heavy when it is at .06 and when rear spar is at from .66 to .67. Within the limits of the curves front spar is lightest when it is at .12 and rear spar at .42; obviously *front* spar gets lighter as rear spar moves forwards and would be zero with rear spar at .28. Rear spar is naturally lightest when front spar is at furthest back position, .16, and when rear spar itself is at about .64. It is interesting to note that rear spar weights increase on either side of some minimum position (from .6 to .64, dependent on front spar position), also that for far forward positions of rear spar this spar is lightest for most *forward* position of front spar, whilst for far back positions of rear spar this spar is lightest for farthest *back* position of front spar. The latter result is obvious, so is the former, of course, when we consider that when the rear spar is forward of .6 it is ahead of chosen centre of pressure, so that the *nearer* the front spar is to it the greater is the *down* load on the front spar.

The most interesting point, however, is the total weight value. The *lightest* condition is given as with front spar at .08 and rear at .42, much more forward positions than in any current practice; from the slope of the curves, moreover, it appears that the total spar weight would be still less for a still more forward position of rear spar. But the curves are very flat and bunched together for all cases when rear spar is ahead of .66 and front spar behind .08. Normal

practice is about .12 for front spar and .62 for rear, and from these curves we get the total weight for this disposition as only about 6 per cent. greater than the minimum. We cannot have too far forward a position for the rear spar in practice, or the rib weight will go up; moreover, narrow ailerons are more efficient than wide ones, so if the rear spar be far forward we must add to the wing a secondary rear spar, behind the main one, for aileron attachment. It is noteworthy that German practice has inclined to a very much farther forward position of main spars than we usually employ, and to the addition of a secondary rear spar for ailerons. It would be interesting to investigate further for the economic position of main spars, including effect on rib weight and weight of secondary rear spar for aileron. Another matter worth investigating would be the effect on aerodynamic efficiency and strength obtained by a far forward rear spar and ribs more or less flexible behind the rear spar; it is conceivable that the automatic variation of camber due to variation of load on the flexible rear portion might be of advantage aerodynamically and that the flexibility itself might improve the strength, or more accurately, perhaps, decrease the danger of failure in the air, though it would not do so under static loading.

(Plate 4.) We now come to the question of the economic position for points of support along the main wing spars.

Firstly, we must decide on how the load may be considered to be distributed along the spar. In the top figure is drawn in full lines what is a fair average to take for the grading off of the load at a wing-tip. AC represents a length equal to the chord of the aerofoil. In dotted lines is drawn what I call an "equivalent rectangle." The area of this rectangle and the moment of its area about BC are practically the same as are area, and moment of area about BC of area below grading curve. The end of the rectangle is .2 of the aerofoil chord short of the spar end. It appears to be sufficiently accurate, therefore, to consider a spar as uniformly loaded to a distance of .2 of the aerofoil chord length from its end. I use this assumption in the few spar length calculations which follow in this paper.

The question of economic positions for points of support is a very highly complicated one; it should mean properly that disposition which will give as a whole the lightest combination of spars, tween-wing struts and wire bracing, for some required strength. I have considered only what disposition of supports will give approximately the same maximum stresses in a spar of uniform cross section throughout. There is no reason to claim that this will give the lightest structure, it might prove more economical to use other positions for points of support and stiffen up the spars locally; but it was impossible in the scope of this paper to undertake a lengthy investigation on this point, and I believe that the uniform section spar disposition is probably about as light as any other.

The five figures below give respectively the positions of points of support for the top and bottom wings of a single bay biplane, for the top wing of a two bay biplane, for the bottom wing of a two bay biplane, for the top wing of a three bay biplane and for the bottom wing of a three bay biplane. At each point of support are given the values of the bending moment and of the vertical reaction, the approximate values of maximum bending moment between points of support are given also.

In the single bay type the disposition is the same for top and bottom wings, because in the top wing the compression is the same all along the spar inside B. In the two and three bay types the points of support are different for top and bottom wings, as the end loads pile up, of course, in the top spars, and there are no compressive end loads (save those due to drift and stagger) in the bottom spars. The points of support for the top wing spars are so arranged that the end loads in a biplane of gap equal to about eight-tenths chord, and added bending moments due to these end loads will, when added to the fixing moments, give the same unital compressive stress in the uniform section spar at each point. I have

assumed that all spars are pin-jointed at their inner ends, as I consider that to be the soundest practice; "fixed joints" in a composite wood and metal structure are generally questionable, especially when detachibility comes in, and one does not know how to consider fairly in calculations a half-hearted type of "fixed" joint.

It is noteworthy that in types of two or more bays the maximum bending moment between any two points of support is never as great as at the points of support. This means that a uniform section spar will be unnecessarily heavy between supports, and it would probably pay to make the spars to strength required between points of support, and stiffen them up locally for some little distance on each side of supports.

(Plate 5.) We now come to the consideration of the tween-wing struts. Shown here are the proportions of what I shall call a "standard strut." The proportions of the cross section are probably about as good from a weight and head resistance point of view as any other. The strut is supposed to be of solid spruce of 32lbs. per cubic foot density, with an ultimate compressive strength of 5,000lbs. per square inch and a value of modulus of elasticity of one and a half million pounds per square inch. The amount of taper has been decided from figures given in the paper by Messrs. Barling and Webb, published in THE AERONAUTICAL JOURNAL of October, 1918.

Here are given for this strut form the values of area, moment of inertia and radius of gyration of cross section in terms of its maximum breadth b. I give in equation (1) the weight in lbs., W, of the strut in terms of its length in inches, L, and its maximum breadth of central cross section in inches, b; and in equation (2) the value for the crippling load in lbs., P, in terms of L and b.

From equations (1) and (2) is obtained equation (3), which gives directly, for purposes of *weight* estimates, the value of W in terms of L and P.

In equation (4) is given an approximate value for the head resistance in lbs. of the strut in terms of v, L and W, where v is the speed in feet per sec. The value is obtained from experimental figures given by the N.P.L.

(Plate 6.) Here are given values for weight and head resistance of tension wires. I have assumed that one can always use a wire of exactly the required amount of cross sectional area. The form of section is constant and is an ellipse with major axis equal to four times minor axis; the density of the material is taken as .284lbs. per cubic inch and the ultimate tensile strength as 45 tons per square inch.

In equation (3) is given the value for W, the weight per foot run in lbs., in terms of P, the ultimate breaking load in lbs.

In equation (4) is given the approximate value for R, the head resistance in lbs. of a wire in terms of v, L and P, where v is speed in feet per sec. and L is length of wire in *feet*.

The weight per wire of necessary end fittings, meaning say two fork joints with pins and lock nuts, may be taken as about $.52/10^4\ P$ in lbs.—this value is obtained from an average of the weights of various different sizes of A.G.S. fork joints, pins and lock nuts.

(Plate 7.) I attempt now, from model data, a simple investigation into comparative size of tail plane required to give longitudinal stability to a monoplane, a "square" biplane and a "staggered" biplane. The aerofoil form is the same throughout. On the figures are shown the five different fore and aft positions, and the constant vertical position of centre of gravity of whole aeroplane considered for each type.

The curves below each type give for it values of pitching moment on a base of angle of incidence for each of the five different positions of centre of gravity.

The pitching moment at any one attitude is the product of the "absolute" coefficient of *total reaction* on the aerofoil (or aerofoils), multiplied by the vertical distance (expressed as a fraction of chord length) of the line of this reaction from the centre of gravity of the whole aeroplane. The curves indicate diving moment

when above the heavy horizontal zero line, and stalling moment when below this line.

The small figures in circles attached to each curve give the fore and aft position of centre of gravity for which the particular curve is drawn.

It is interesting to note how the range of pitching moment decreases as the centre of gravity is moved forwards, also that it is, on the whole, less for the "square" biplane than for the monoplane and less for the "staggered" than for the "square" biplane.

These figures are all obtained directly from experiments made by the N.P.L. on model aerofoils of 18in. span × 3in. chord at 40 f.p.s.; no attempt has been made to correct for "full size" conditions. The correction required would be almost entirely due to increased lift coefficient values (especially at small angles of incidence) for "full size" conditions; the values for centre of pressure position would be practically unaltered. As model figures are used also when considering the tail required for stability, the increase in lift coefficient value due to change from model to "full size" conditions may, I think, be considered to alter by about the same amount for both aerofoils and tail; that is to say, the same proportions of tail should produce about the same results for both model and full size machines.

(Plate 8.) On this plate are given the three different forms of tail plane investigated. Case I. is a "symmetrical section" tail, Case II. a "wing form" tail with its convexity downwards, Case III. the same "wing form" tail, but with its convexity upwards.

You will note that I have assumed a constant position for centre of reaction on the tail, which is accurate enough for our purpose as the tail chord is small compared to distance of tail from C.G. I have taken that the distance of this assumed fixed centre of reaction on the tail is a distance from centre of gravity of aeroplane of amount equal to two and one half times the chord length of the aerofoil or aerofoils. I have also, for simplicity in calculating the tail moment, assumed that the chord of the tail when produced passes through the centre of gravity of the aeroplane.

Figures for all three tails are taken directly from N.P.L. figures for models of 18in. span × 3in. chord at 40 f.p.s., and both the "wing form" tails are of the same form as the main aerofoils.

I have next proceeded to find the smallest size for each of these three forms of tail which would make each of these three aeroplanes just stable for each of its five positions of centre of gravity, *assuming the tail to be in undisturbed air.*

The method used was as follows:—On tracing cloth I drew out a series of curves of "tail moment" on a base of angle of incidence of tail. As the chord of the tail points at the C.G it was necessary only to consider the normal force on it. The "tail moment," therefore, for any particular angle of incidence *for the tail,* is the product of the "absolute" normal force coefficient for this incidence, multiplied by 2.5 multiplied by a. a, the area value of tail, is taken as a fraction of the main aerofoil (or aerofoils) area. Of course the same scales were used in drawing these tail moment curves as were used for the pitching moment curves.

For each tail then were run a series of curves with values for a, varying from .02 to .07.

I assumed that the aeroplane is to "trim" at $+2°$ incidence for main aerofoils. So a tail moment family of curves was slid over each of the pitching moment curves in turn, and thence, by interpolation if necessary, was found the particular tail curve which, when intersecting the pitching moment curve at $+2°$, would just lie altogether *above* the pitching moment curve to left hand side of intersection and altogether *below* pitching moment curve to right hand side of intersection. (*Plate 7 again.*)

I have not shown the series of tail moment curves employed, but on the monoplane pitching moment diagram are shown a few selected curves of tail

moment. Intersecting the .30 C.G pitching moment curve at $+2°$ is shown, in dotted line, the moment for a symmetrical tail of area = .025 main aerofoil area. This curve cuts the base line at $+8.9°$. Therefore with this tail set at $-8.9°$ to the aerofoil chord the aeroplane will just be stable; you will note that there is a neutral spot at $+6.5°$. Also intersecting the .30 C.G pitching moment curve at $+2°$ is shown, in dot and dash line, the moment for a "wing form" tail "convex-down" of area = .025 main aerofoil area. This curve also cuts the base line at about $+8.9°$. Therefore with the chord of this tail at $-6.5°$ (its zero lift is at $+2.4°$) to the aerofoil chord the aeroplane will just be stable; you will note that again there is a neutral spot at $+6.5°$, and that with this "convex-down" tail the stabilising moment is greater for nose diving and less for stalling than it is with the symmetrical tail of same area.

On the .36 C.G pitching moment curve is drawn, in dotted line, the moment curve for a symmetrical tail of area = .038 main aerofoil area, set at $-3.2°$ to chord of main aerofoil. This gives stability with a neutral point at $+14°$.

On the .42 C.G pitching moment curve is drawn, in dotted line, the moment curve for a symmetrical tail of area = .064 main aerofoil area, set at $-1.4°$ to chord of main aerofoil. This gives stability with a neutral spot at about $+13\frac{1}{2}°$. Also on the .42 C.G pitching moment curve is drawn, in dot and dash line, the moment curve for a "convex-up" tail of .064 main aerofoil area, set at $-3.5°$ (its zero lift is at $-2.4°$) to main aerofoil chord. This gives stability with a neutral spot at $-4.5°$. You will note that with the "convex-up" tail the stabilising moment is greater for stalling and smaller for nose-diving than with the symmetrical tail. We cannot give more time to consideration of the method employed, I hope this brief explanation is sufficient.

(*Plate 8 again.*) We have then values for size of tail plane required, and required setting for chord of tail relatively to chord of main aerofoil, *considering the tail as in undisturbed air.* These values are given in the curves at the bottom of this Plate 8.

We must proceed to the consideration of what will be the added drag due to tail.

I have made a very rough assumption as a start, namely, that due to the downwash from the main aerofoils we must employ a tail of twice the area found necessary in undisturbed air. As a matter of fact this is pretty nearly correct, and at any rate is quite a fair assumption for a comparative investigation, which is all that this claims to be. I have taken the "absolute" drag coefficients for tail from the curves at the top of the Plate 8. For any one case then the tail drag is taken as area of tail (expressed as a fraction of main aerofoil area) multiplied by "absolute" drag coefficient proper to tail, and divided by "absolute" drag coefficient proper to main aerofoil. This gives us a value for tail drag expressed as a fraction of the main aerofoil drag.

But this is not the "total drag due to tail," for if the tail has to exert a downward force for stabilising, the wings must exert a lift over and above total weight of aeroplane of amount equal to down load on tail, and this added lift must be paid for by added drag. Similarly, if the tail has to exert an upward force for stabilising, the lift of the wings will be less than the total weight of the aeroplane by an amount equal to lift of tail, and this decrease of wing lift gives decrease of drag. The amount of the necessary addition to, or subtraction from, lift of wings, for any one condition, is given by:—Value for pitching moment divided by tail lever; so it is worthy of note that a long tailed machine will, at high speeds at any rate, have a smaller increment of wing drag due to tail down load than will a short tailed machine.

We arrive then at results for total drag "due to tail," being sum of tail drag plus increment of wing drag due to tail down load.

Curves H, J and K give respectively total drag due to necessary "symmetrical," "convex-down" and "convex-up" tails for a monoplane, when the incidence of main aerofoil is $0°$, that is to say, at high speed. Curves L, M and

N give respectively total drags due to same tails, when incidence of main aerofoil is + 4°, that is to say, at approximately climbing or cruising condition.

Curve H_1 is total drag "due to tail" for "square" biplane with incidence of main planes 0°, Curve H_2 is ditto for "staggered" biplane. Curve L_1 is total "drag due to tail" for "square" biplane with incidence of main wings + 4°, and Curve L_2 is ditto for "staggered" biplane.

Accordingly, to these curves we find that for a monoplane the best condition for high speed is to have the C.G at about .325 and to use a "convex-down" tail, whilst the best condition for climb is to have the C.G at about .35 and to use a symmetrical tail. Probably the best all round condition would be to have C.G at about .34 and use a symmetrical tail; this tail would, according to Curve A, need to be .028 × 2, or .056 of the area of the main aerofoil, and, according to Curve D, would need to be set at virtually — 4.6° to main aerofoil, meaning about — 2° actually, to allow for downwash. For the two biplanes are drawn curves for "symmetrical" type of tail only, as it appears to be at least as good as either of the other two types for the monoplane.

For the "square" biplane the best condition for high speed is to have the C.G at about .385, and for climb to have the C.G at about .37. For the "staggered" biplane the best condition for high speed is to have the C.G at about .40, and for climb at about the same position.

It is important to bear in mind that the fore and aft positions of centre of gravity, which I have quoted, refer to the figures on Plate 7. (*Plate 7 again.*) It is obvious that if we raised or lowered the C.G the results would be altered. Up in the top left hand corner are drawn, for the monoplane only, lines representing in direction and magnitude the total reaction at angles of incidence varying from — 6° to + 18°. The general trend of these lines is to converge when produced downwards, meaning that the lower the C.G the better the stability considered statically, if one may so express it. But in practice a low C.G means probably a high moment of inertia, and this in excess gives slowness on control and dangerous pitching. It should also be noted that the quoted fore and aft position of C.G for the "staggered" biplane is measured from the fore end of an arbitrarily assumed "mean chord."

One other point should be noted, namely, that I have omitted the question of weight of tail; obviously, the larger the tail the heavier, and the weight of the tail has to be paid in wing drag. It would be a very small factor, perhaps almost negligible, but it means that one should incline to a slightly farther forward position of C.G and therefore a slightly smaller tail than is indicated as best condition by these curves.

Finally, all these tails are of 6 to 1 aspect ratio, so if in practice a smaller aspect ratio be employed, then must a somewhat larger area be used to offset the decreased value of lift coefficient.

(Plate 9.) Next comes a rather limited investigation into the controlling power of ailerons, or wing flaps. I have worked directly from figures given by the N.P.L. from experiments on a model aerofoil of 18in. span × 3in. chord, at a wind speed of 40 f.p.s., with flap extending for its whole length. Unfortunately, the moment of the model flap, about its hinge, is so small that the percentage of experimental error is sure to be high.

The investigation is for two breadths of flap, Case I. (narrow flap) with flap .22 of aerofoil chord, Case II. (wide flap) with flap .385 of aerofoil chord.

The method adopted is as follows:—For both cases I have taken that the length of leverage on the flaps for the control cables (*i.e.*, AD and AE in the figures) is constant, and equal to .0733 of the aerofoil chord. For both cases I have assumed that the length of the pilot's control pillar (HK in the figure) is constant and equal to .4 of the aerofoil chord, that the maximum lateral angular movement of this control pillar is 15° on each side of the vertical, and that the maximum applied lateral force (at K) is 50lbs.

For both cases I have assumed that the cable attachment lug, JJ, may be

adjusted to such vertical position on the control pillar as is required to give the specified maximum up and down range of flap movement, $-\alpha$ and $+\alpha$ in figure.

I have assumed that all bearings are frictionless.

I have made out, for each case, two tables of "flap values," one table with aerofoil at 0° incidence and one with it at + 12° incidence; only one is reproduced here, that for the wide flap, with incidence of + 12° for aerofoil. In the first column is given angular setting *of flap*, zero being of course when it forms the normal tail end of the aerofoil section.

In the second column is given value of "absolute" lift coefficient for whole aerofoil with flap. In the third column is given value of *added* lift coefficient, obtained by subtracting the lift coefficient for zero flap angle from all the lift coefficient values. In the fourth column is given the value of M, the moment in foot/lbs. of the wind force on the flap about its hinge. In the fifth column is given the added lift in lbs. on the whole aerofoil with flap, obtained by multiplying the added lift coefficient by 1.422. In the sixth column is given the value for t, the tension in the control wire (D.G. or E.F.), obtained by multiplying M by 54.5; it should be noted that if t be positive then wire E.F. is in tension, whilst if t be negative then wire D.G. is in tension. In the seventh column is given the value of l divided by t, which is the measure of difference in lift on the whole aerofoil corresponding to a certain tension in the control wire. It is notable that if a system were possible in which the flap on one side at a time of a machine could be pulled up, whilst the other flap remained in normal position, such system would give a very light control load on the pilot, for the flap has an upward wind load on it until it is at — 10°. It is also of note that, with the standard practice of interconnected double acting flaps, up to a flap setting of + and — 10°, the rising flap helps to pull the other down, whilst beyond this range, tension must be applied to pull the rising flap higher as well as to pull the falling flap lower.

In the eighth column is given the value of flap setting, $\pm\alpha$, for *two* aerofoils, one with flap down, the other with flap up. In the ninth column is given the value in lbs. of f, the sum of the value of the *added* lift in lbs. on the aerofoil with flap at $+\alpha$, plus the value of the *decreased* lift in lbs. on the aerofoil with flap at $-\alpha$; f is thus a measure, in lbs., of the total up and down forces produced on both aerofoils together by a flap setting of + and $-\alpha$. In the tenth column is given the value of p in lbs., where p is the actual pull which must be given to the control wires (irrespective of balanced tensions), to produce flap positions of + and $-\alpha$; it is obtained by subtracting the values of t for $+\alpha$ values from the values of t for the corresponding $-\alpha$ values.

In the last column is given the value of f divided by p, which is a measure of flap "efficiency," as it is the ratio of the total up and down forces produced on the two aerofoils, to the force which must be applied to the control wires in so doing. It is noticeable how this "efficiency" drops as the range of flap movement is increased, due to the fact that the wind reaction on the rising flap is an upward and decreasing load to — 10°, and then becomes a downward and increasing one.

Having obtained these four tables of "flap values" I have proceeded to apply them to a full size machine.

I have considered a biplane of equal top and bottom wings of 6ft. chord, with double acting flaps of the same size on top and bottom wings. I have taken that the speed when incidence of wings is zero is 160 f.p.s. (about 109 m.p.h.), and therefore that the speed when incidence of wings is + 12° is 72.2 f.p.s. (about 49 m.p.h.); I have assumed that the "absolute" lift coefficient values for the full size biplane are the same as for the model monoplane.

I have employed the "standard" form of wing tip and have considered that the wings are uniformly loaded to within 1.9 feet of their tips, as shown; I have

also assumed that the up and down forces on uniformly loaded length of wing with flap, and the moment of uniformly loaded length of flap about its hinge, may be taken from model figures (for an 18in. span × 3in. chord monoplane with flap all along it) by direct substitution of areas and squares of speeds.

On these assumptions we get the equations given here for the full size biplane.

First we get an expression for the load which a lateral force of 50lbs. at top of control pillar, *i.e.*, at K, will produce in the flap control wires, for a required maximum value of up and down flap setting when the control lever is at 15° to one side; this obviously varies inversely as the flap setting, and is of amount $4{,}090/a$ in lbs., where a is the angular up and down flap setting in degrees. This load will produce a total sum of up and down forces on the wings of amount $(4{,}090/a) \times f/p$, where f/p is the "flap efficiency" value proper to flap setting of $+$ and $-a$, and is taken from one of the tables of "flap values" for model.

We also obtain the result that if y be the length in feet of each of the four flaps, speed be 72.2 f.p.s. and incidence $+12°$

$$\text{then } y = \frac{39.1}{p \times a}$$

whilst if the speed be 160 f.p.s., and incidence 0°

$$\text{then } y = \frac{7.96}{p \times a} \quad \text{or} \quad a = \frac{7.96}{p \times y}$$

where p is the proper value for "resultant tension in control wire," taken from one of the tables of "flap values" for model.

The curves given here are for the full size machine:—Curve P gives applied tension in flap control wires; Curve FN gives resultant sum of up and down forces on the total uniformly loaded lengths of wing with narrow flap; Curve FW gives the same for broad flap; Curve LN gives the required length in feet for each of four narrow flaps; Curve LW the same for each of four broad flaps. All these curves are drawn on a base of value of maximum flap setting.

Now the controlling power is the rolling moment produced by the flap setting, and this is the product of the "sum of up and down forces" multiplied by leverage. I have taken the leverage as one half of the distance between the centres of the uniformly loaded lengths of right hand and left hand flaps.

The top planes of two biplanes are shown here, a "short span" and a "long span." On these are drawn the flap sizes, both narrow and wide, which by a load of 50lbs. applied at the top of the pilot's control column will, when the machine is flying at $+12°$ and at 72.2 f.p.s., be pulled respectively to $\pm 30°$, $\pm 20°$, $\pm 15°$, $\pm 10°$.

The leverages for rolling moment are obtained from these plan views, and thence the values for rolling moment.

Curve R.M.N.S. 12 is rolling moment for "short span" biplane with narrow flaps flying at $+12°$ incidence; Curve R.M.W.S. 12 is for same, but with wide flaps. Curve R.M.N.L. 12 is for "long span" biplane with narrow flaps, flying at 12° incidence; Curve R.M.W.L. 12 is for same, but with wide flaps.

Curve R.M.N.L.O. is for the "long span" biplane with narrow flaps flying at 0° incidence; Curve R.M.W.L.O. is for same, but with wide flaps. On these last two curves are appended in circles the angle to which the flaps (which at $+12°$ incidence can be pulled up and down to the abcissæ values for flap setting) can be pulled when the machine is flying at 0°.

As a result of the methods we have applied we find that, except in the case of the "short span" biplane with narrow flaps, it would appear to pay to use flaps as long as possible. The most efficient flaps appear to be "C" narrow,

or " J " wide, for the " short span " biplane, and " K^1 " narrow, or " J^1 " wide. for the " long span " biplane.

Of course, as I remarked before, there is the probability of a high percentage of experimental error in the flap moments, and neither friction nor inertia have been taken into account.

Naturally the larger the flaps the greater would be their inertia, the greater would be the balanced tension in the control wires and the greater therefore the friction in the moving parts of the control system. So even if we assume that our model data are correct and the deductions made from them sound, it is probable that in practice it would prove better to use somewhat smaller flaps than are indicated as the best from this investigation. But it certainly seems correct to use narrow flaps and to make these flaps sufficiently long so as not to have to work them through too large a range.

I should have liked to look into the case of a biplane with flaps on the top wing only, as this system has some structural advantages. But, unfortunately, the only model data I have been able to obtain deal only with the case of pulling *down* the flap on the top wing of a biplane, and rather condemn the system for inefficiency on the results. To investigate the rolling moment we should need also the results with flap pulled up. I am inclined to believe that sufficiently long flaps on the top wing only of a biplane, pulled up and down of course, should give quite efficient lateral control, particularly if the top wing be larger than the bottom and if the machine be of smallish span.

I now come to the final subject of which I have attempted a simple investigation. It is the comparison of different types of biplane structure.

(Plate 10.) Here are three biplanes with differing types of wing structure:—(A) is a single bay type with " mean " aspect ratio of 5 for top and bottom wings; (B) is a two bay type, " mean " aspect ratio 7; (C) is a three bay type, " mean " aspect ratio 9.

The comic rakes for all the tween-wing struts have been perpetrated in order to obtain what the previous investigation gave as " economical " position of points of support for the spars of both top and bottom wings.

The wing areas for these three types have been arrived at by assuming that the total weight is the same for all three, and that the stalling speed near the ground is to be the same for all three, and using the maximum " absolute " lift coefficient values proper to the different aspect ratios from the " full size " aerofoil curves given previously, Plate 1. The maximum " absolute " lift coefficients are .535 for biplane (A), .543 for biplane (B) and .550 for biplane (C). Assuming total weight of each machine to be 2,600lbs., (A) with its 375 sq. ft., has a wing loading of 6.94lbs. sq. ft.; (B) with its 369 sq. ft., a loading of 7.05; and (C) with its 364 sq. ft., a loading of 7.15. For all three, therefore, the stalling speed near the ground is about 50 m.p.h.

Approximate calculations for the weight of the wing structure for each type were then made, using the following methods:—Total load for stress taken as 2,200lbs., C.P. taken at .28 for stress on front spars. Spars, struts and tension wires, section and end shape of aerofoils, all taken as of " standard " forms previously described. Weights of top front spar were obtained by finding bending moment and end load just inside point B; the bending moment was multiplied by 1.2 for (A), by 1.15 for (B) and by 1.10 for (C), to allow for increment due to end load. The necessary breadth, and hence cross sectional area of " standard " I. section front spar was found which would give a maximum fibre stress of 800lbs./sq. ins. when subjected to this total bending moment and end load, and it was assumed that this section was constant throughout the spar length, and that the timber was of 32lbs. per cubic foot density. From the previously given curves of spar weights the weight of rear spar was taken as 4/3 times that of front spar.

For the bottom front spars, the weights were obtained by finding the necessary breadth, and hence cross sectional area, of " standard " I. section spar which would give a maximum fibre stress of 800lbs. per square inch when subjected simply to bending moment at outer support, and assuming this section constant throughout spar length, and density of wood 32lbs. per cubic foot. For bottom rear spars, the weights were taken as 4/3 times those of front.

Weights of ribs were taken as proportional to square of chord length, and it was assumed that the weight of a rib of 6 feet chord length would be ½lb. and that the rib spacing would be 12in. in all cases.

Weight of covering was taken as 20zs. per square foot of *wing* surface, meaning 10z. per square foot of covering.

Total weight of leading edge, trailing edge and spacing battens was taken as the same *per foot run* in all cases, and as of .28lbs. weight per foot run. Weight of nosing ribs was taken as varying directly as chord of wing, and it was assumed that the number of nosing ribs was twice that of the ordinary ribs and that 36 nosing ribs for a wing of 6 foot chord would weigh 1lb.

Weight of compression members was taken as .4lbs. per foot run for all cases. It was assumed that for case (A) there were 16 compression members in the two top wings and top centre plane, and 10 in the two bottom wings; that for case (B) there were 17 in the two top wings and top centre plane, and 12 in the two bottom wings; that for case (C) there were 21 in the two top wings and top centre plane, and 16 in the two bottom wings.

The weight of top wing spar fittings, at strut ends, was got by assuming that the weight of a fitting varies directly as the pull of the lift wires attached to it, and that a suitable fitting to take an ultimate lift wire pull of 7,000lbs. would weigh 1lb. The weight of the top centre plane spar fittings, at strut ends, was taken as same as that for top wing spar fitting at end of inner strut. The weight of each bottom wing spar fitting at a strut end was taken as two-thirds of the weight of the corresponding top wing spar fitting. The weight of the fitting at the inner end of each wing spar, and at each end of each top centre plane spar, was taken as ½lb. in all cases. The weight of internal bracing wires was taken as .7 of the weight of compression members.

The weight of the front tween-wing struts was obtained from the previously given formula (Plate 5), the ultimate load being taken as seven times the normal flying load with C.P. at .28; the rear struts were taken as of same weight as the corresponding front struts.

The weight of the front centre plane struts was obtained by assuming that a vertical down load equal to the total load for stress minus that fraction of it applied at the inner end attachments of the bottom wings, was to be taken equally by these two struts, and that their crippling load would be three times the resultant. The rear centre plane struts were taken as of the same weight as the front.

The weights of the front lift wires were obtained from the previously given formula (Plate 6); each front lift wire having an ultimate tensile strength of eight times the normal flying load with C.P. at .28. Rear lift wires were taken as of same weight as front, and ground wires as of one half the weight per foot as that of corresponding lift wires. The wing bay incidence wires were taken as of same weight per foot as that of the ground wires in the bay inside and next to them. The top centre plane cross bracing and incidence wires were taken as half the weight per foot as that of the inner lift wires.

Weights of strut end fittings were taken as one tenth weight of struts, and weights of end fittings proper to wires from previously given equation, Plate 6.

I have devoted considerable space to this rather uninteresting description of methods, but it was advisable to do so in case any misapprehension should be occasioned.

The weights obtained by these methods are as follows:—

	Case (A).	Case (B).	Case (C).
Two top wings and top centre plane	(50.3%) 180 lbs.	(48.7%) 168 lbs.	(46.2%) 153 lbs.
Two bottom wings	(29.9%) 107 lbs.	(27.8%) 96 lbs.	(29%) 96 lbs.
All struts	(10.3%) 37 lbs.	(11.6%) 40 lbs.	(11.5%) 38 lbs.
All wires	(9.5%) 34 lbs.	(11.9%) 41 lbs.	(13.3%) 44 lbs.
Total	358 lbs.	345 lbs.	331 lbs.

It will be seen that the weights are very much the same for all three types, (B) being about $3\frac{1}{2}\%$ lighter than (A) and (C) about $7\frac{1}{2}\%$ lighter than (A).

As Case (C) gives a very shallow girder depth, I thought it advisable to find the alteration of weight due to increasing the gap, using of course the same methods as before. Increasing the gap will have the effect of lightening the top wing spars and the spar fittings of both wings, of increasing the weight of the struts, and of decreasing the weight *per foot* of the tension wires but increasing their length; all other parts remain unaltered in weight. Three more cases were investigated, (C_1) with gap equal to top wing chord, (C_2) with gap equal to 1.2 times top wing chord, (C_3) with gap equal to 1.4 times top wing chord. (C_1), (C_2) and (C_3) were in other respects the same as (C).

The weights obtained were:—

	Case (C_1).	Case (C_2).	Case (C_3).
Two top wings and top centre plane	(42.9%) 148 lbs.	(39.4%) 142 lbs.	(35.9%) 141 lbs.
Two bottom wings	(27.5%) 95 lbs.	(26.1%) 95 lbs.	(23.9%) 94 lbs.
All struts	(17.1%) 59 lbs.	(22.8%) 82 lbs.	(29%) 114 lbs.
All wires	(12.5%) 43 lbs.	(11.7%) 42 lbs.	(11.2%) 44 lbs.
Total	345 lbs.	360 lbs.	393 lbs.

This gives the somewhat unexpected result that increasing the gap increases the total weight of wing structure, as the increase of strut weight is considerably greater than the decrease in spar and spar fitting weights, whilst the weight of the tension wires remains almost unaltered.

Having obtained comparative weights for the wing structures of these various types, I have proceeded to obtain figures for comparative head resistance of struts and wires for each case, by applying the formulæ as given before, Plates 5 and 6. The following are figures for the head resistance in lbs. at a wind speed of 100 feet per second:—

	Case (A).	Case (B).	Case (C).	Case (C_1).	Case (C_2).	Case (C_3).
All struts ...	7.6	8.8	9.1	13.04	17.11	22.32
All wires ...	7.9	9.5	10.6	10.85	11.44	12.33
Total ...	15.5	18.3	19.7	23.89	28.55	34.65

The final quality compared was the moment of inertia of total wing structure about the fore and aft axis through C.G. of aeroplane. For this I assumed that the C.G. of the 2,200lbs. weight of the whole aeroplane, *less* wing structure,

was situated in the centre of the square cross section of the body in all cases. This gave the following figures:—

	Case (A).	Case (B).	Case (C).	
Height of total C.G. above bottom of body	1.57′	1.49′	1.42′	
Moment of inertia of two top wings and top centre plane	(57.2%) 21,170	(55.7%) 24,480	(51.9%) 26,360	In lbs. × ft.²
Moment of inertia of two bottom wings	(27.7%) 10,270	(28.2%) 12,400	(31.7%) 16,080	In lbs. × ft.²
Moment of inertia of all struts	(9.3%) 3,440	(9.5%) 4,150	(9.1%) 4,610	In lbs. × ft.²
Moment of inertia of all wires	(5.8%) 2,160	2,910	3,700	In lbs. × ft.²
Total moment of inertia of wing structure	(100%) 37,040	(100%) 43,940	(100%) 50,750	

In obtaining these figures the wings were considered as homogeneous lamina, the struts and wires as homogeneous thin bars.

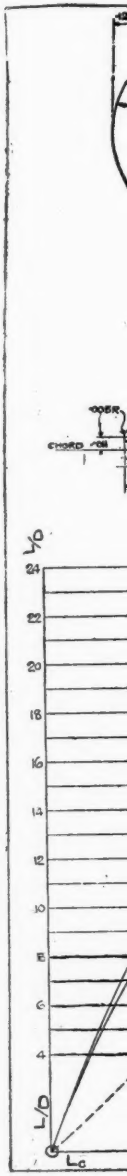
It only remains, from the foregoing data, to consider the comparative performances of these different types of biplanes. The following assumptions are made:—Everything except wing structure, tail size and fuel capacity, exactly same for all cases. The 2,200lbs. weight to include 50 gallons petrol and an engine of 300 h.p. (using .6 pints per B.H.P. hour on full throttle). To bring machines (A), (B) and (C) to the 2,600lbs. total weight, and therefore to the 50 m.p.h. stalling speed initially decided upon, we shall add petrol; Case (A) will therefore carry 50+6=56 gallons petrol, Case (B) 50+8=58 gallons, Case (C) 50+10=60 gallons.

We shall take the "total drag due to tail" for Case (A) to be .13 aerofoil drag at full speed and .052 aerofoil drag at climbing speed, and thence for Case (B) to be .108 at full speed and .043 at climbing speed, and for Cases (C), (C_1), (C_2) and (C_3) to be .093 at full speed and .037 at climbing speed; the variation in tail drag is arrived at by assuming that as the tail lever is constant and the wing area approximately constant, the pitching moment (and therefore required size of tail for stability) will vary directly as the wing chord, hence total "drag due to tail" will vary also directly as wing chord. Thrust horse-power at full speed 240 in all cases, and thrust horse-power climbing at 70 m.p.h. 180 in all cases. Head resistance of all other parts of the aeroplane, except wing structure and tail, 80lbs. at 100 f.p.s. and to vary as the square of the speed.

	Case (A).	Case (B).	Case (C).
Maximum speed ...	139.7	139.3	139.1 m.p.h.
Duration at full speed ...	2.49	2.58	2.67 hours
,, ,, ,, ...	348	360	372 miles
Initial climbing rate ...	1610	1660	1710 ft./min.
*Duration at 90 m.p.h. ...	4.24	4.71 (11%)	5.06 hours (20%)
,, ,, ,, ...	381	424	455 miles

Cases (C_1), (C_2) and (C_3) must be considered somewhat differently, for as they are of increasing gap value, but of constant wing area value, if we stick to the 2,600lbs. total weight, then their stalling speeds will be lower than the 50 m.p.h. decided upon. On the other hand, if we increase the weights as required to maintain the 50 m.p.h. stalling speed, we shall slightly decrease the strength. As a comparison, I have elected to stick to the 50 m.p.h. stalling speed, and I have assumed that the variation of lift coefficient values and of lift over drag

* Propeller efficiency taken as .8, petrol consumption at 1.0 pints/B.H.P. hr.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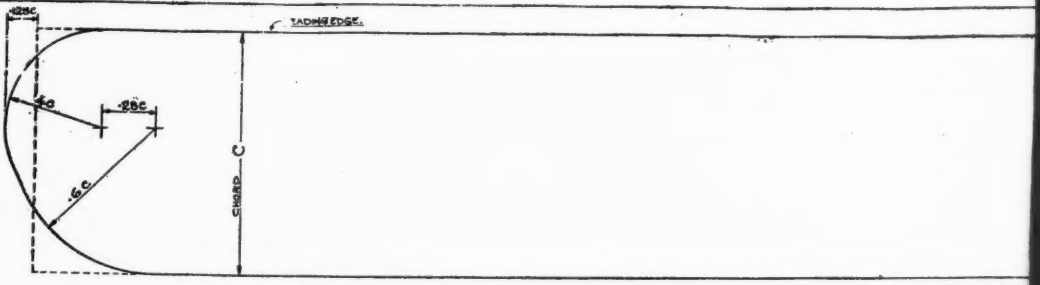
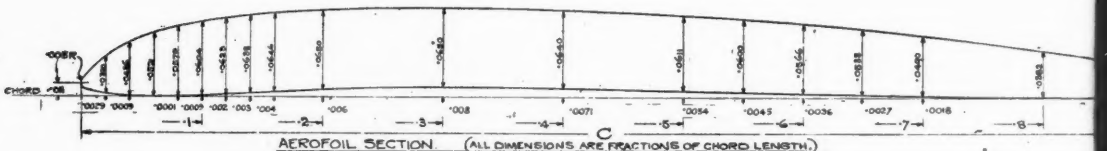
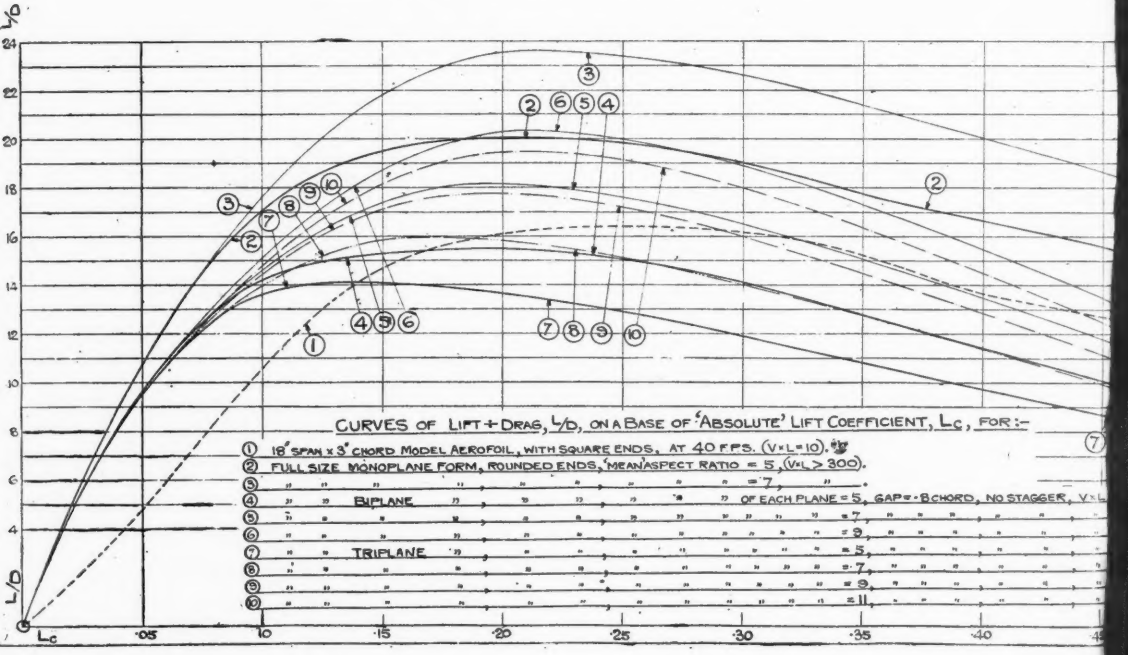


PLAN FORM OF AEROFOIL, WITH ROUNDED ENDS. 'MEAN' ASPECT RATIO = $\frac{\text{AREA}}{C^2}$. AREA = (EXTREME SPAN − ·2 i.e. MEAN SPAN.



AEROFOIL SECTION (ALL DIMENSIONS ARE FRACTIONS OF CHORD LENGTH.)



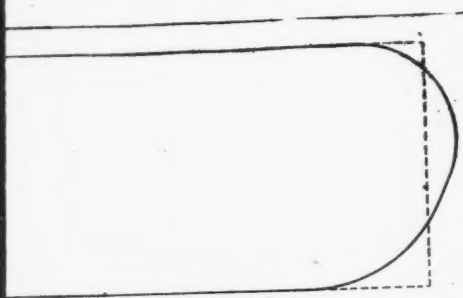
CURVES OF LIFT ÷ DRAG, L/D, ON A BASE OF 'ABSOLUTE' LIFT COEFFICIENT, L_C, FOR:-

① 18' SPAN x 3' CHORD MODEL AEROFOIL, WITH SQUARE ENDS, AT 40 F.P.S. (V×L=10).

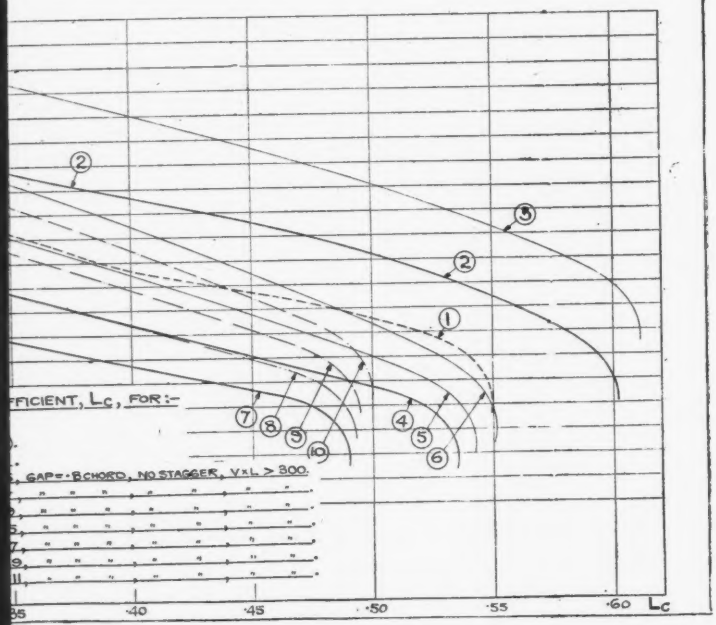
② FULL SIZE MONOPLANE FORM, ROUNDED ENDS, 'MEAN' ASPECT RATIO = 5, (V×L > 300).

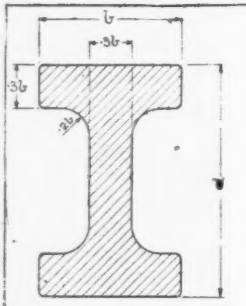
③④⑤⑥⑦⑧⑨⑩ BIPLANE " " "

PLATE I



AREA / C_P . AREA = $\frac{(\text{EXTREME SPAN} - \cdot 25C)}{\text{I.E. MEAN SPAN.}} AC$



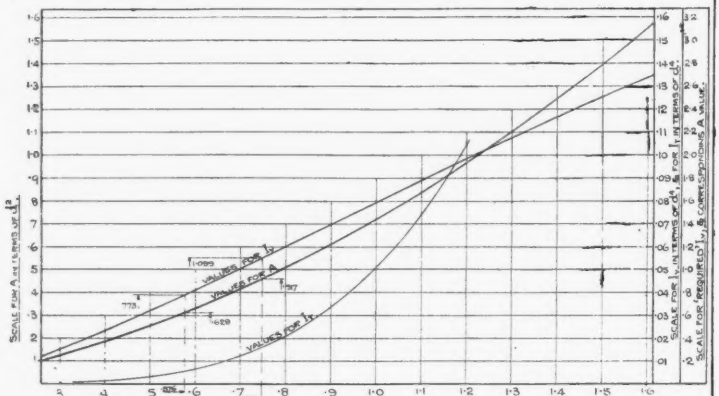


STANDARD CROSS SECTION FOR WING SPARS.

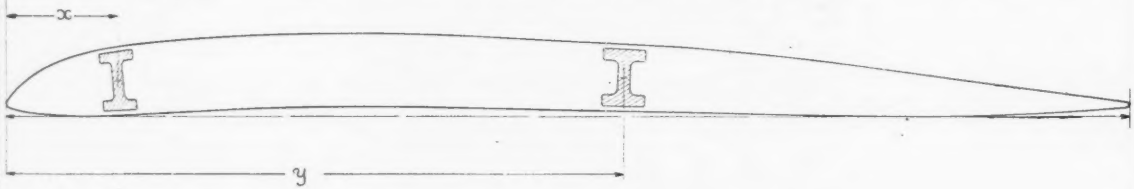
$A = \cdot 3bd + \cdot 42b^2$

$I_V = \cdot 025bd^3 + \cdot 105b^2d^2 - \cdot 063b^3d + \cdot 0126b^4$

$I_T = \cdot 04865b^4 + \cdot 00225db^3$


SCALE FOR A, IN TERMS OF d²
SCALE FOR I_V IN TERMS OF d⁴, & FOR I_T IN TERMS OF d⁴
SCALE FOR REQUIRED I_V & I_T IN CORRESPONDING A VALUE
VALUES FOR I_V
VALUES FOR A
VALUES FOR I_T
1·089
·773
·627
·629
·282
SCALE FOR RATIO b÷d.

CURVES OF AREA OF SECTION, A, OF VERTICAL MOMENT OF INERTIA, I_V, & OF TRANSVERSE MOMENT OF INERTIA, I_T, ON A BASE OF RATIO b÷d.



SPAR WEIGHT TABLE FOR FRONT SPAR AT ·10, REAR SPAR AT ·50, ·54, ·58, ·62, ·66 & ·70

C.P TAKEN AS AT ·28 FOR FRONT SPAR & AS AT ·60 FOR REAR SPAR. 'FACTOR OF SAFETY' FOR REAR SPAR TAKEN AS ·75 THAT FOR FRONT.

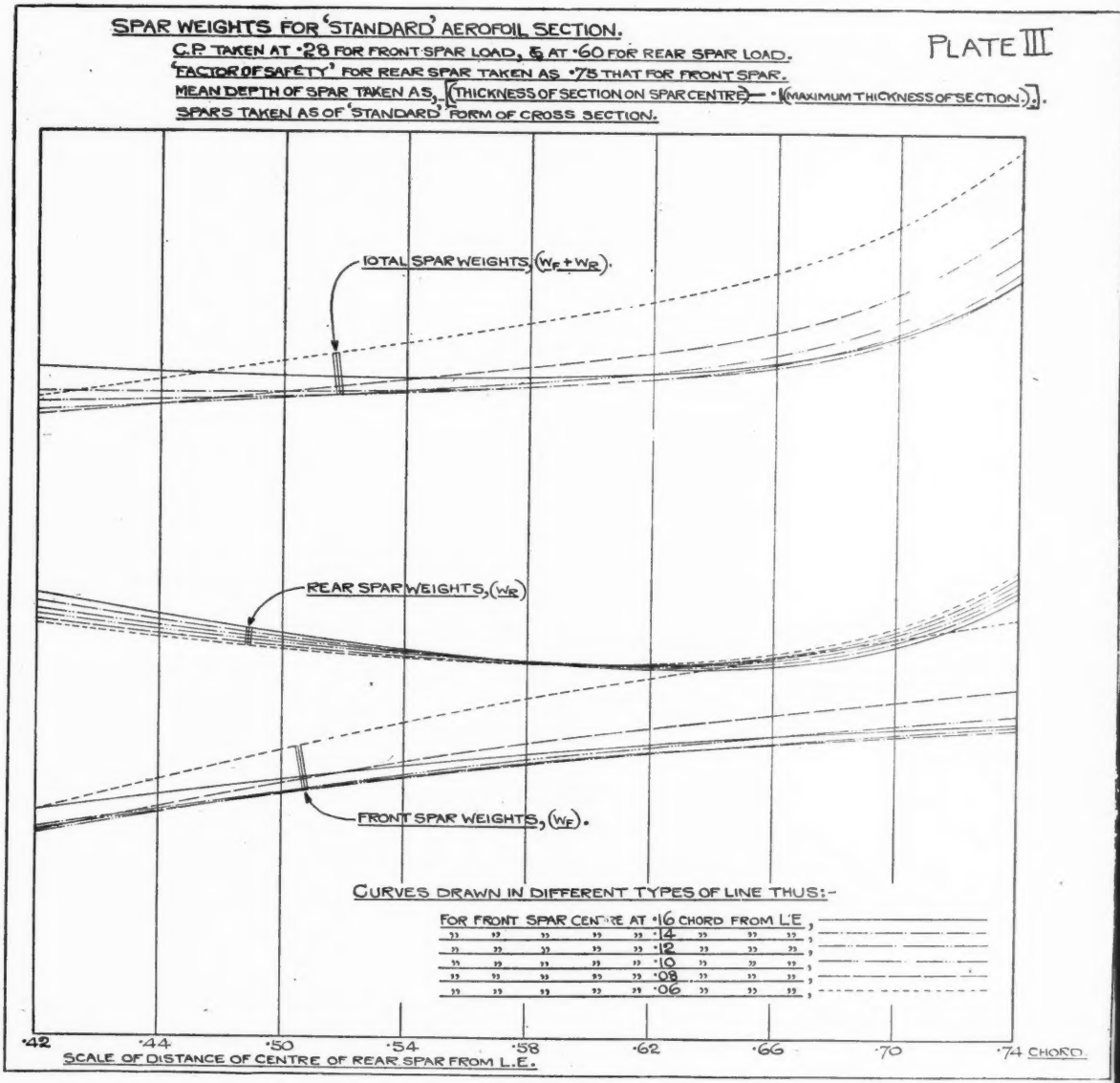
FRONT SPAR AT ·10 $(d_F = \cdot 1828,\ d_F^2 = \cdot 880,\ d_F^4 = \cdot 726,\ (d_F^4 \div d_R^4) \times 3 = \cdot 726)$

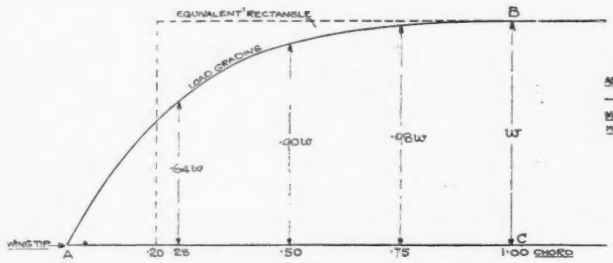
(I) REAR SPAR AT	(II) d_R	(III) d_R^2	(IV) d_R^4	(V) $\frac{2d_R^2 + d_F^2}{3}$	(VI) L_F	(VII) REQUIRED I = (VI) ÷ ·769	(VIII) CORRESPONDING VALUE ON A CURVE	(IX) b/d FRONT SPAR	(X) $W_F = \frac{(VIII) \times \cdot 85}{\cdot 2828} A$	(XI) L_R	(XII) REQUIRED I $= \frac{(XI) \div \cdot 75}{\cdot 077}$	(XIII) CORRESPONDING VALUE ON A CURVE	(XIV) b/d REAR SPAR	(XV) $W_R = \frac{(XIII) \times (XII)}{\cdot 2828}$	(XVI) WT $(W_F + W_R)$
·50	·950	·902	·814	·843	·550	·719	·563	·547	·784	1·200	1·069	·889	·731	1·268	2·052
·54	·922	·850	·723	·765	·591	·773	·629	·576	·845	1·120	1·099	·917	·747	1·231	2·076
·58	·885	·783	·613	·670	·625	·817	·666	·601	·895	1·040	1·164	·983	·781	1·216	2·111
·62	·845	·714	·510	·578	·654	·855	·698	·621	·938	·962	1·249	1·064	·824	1·200	2·138
·66	·793	·629	·396	·474	·679	·887	·728	·638	·979	·893	1·415	1·234	·907	1·229	2·208
·70	·736	·542	·294	·377	·700	·915	·751	·651	1·010	·833	1·658	1·517	1·034	1·300	2·310

PLATE II

HILL REFERENCE LIBRARY ST. PAUL

PLATE III

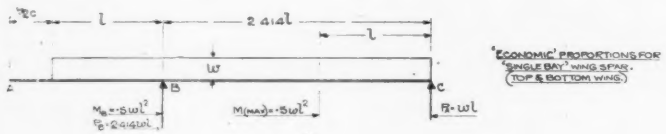

SPAR WEIGHTS FOR 'STANDARD' AEROFOIL SECTION.
C.P. TAKEN AT ·28 FOR FRONT SPAR LOAD, & AT ·60 FOR REAR SPAR LOAD.
'FACTOR OF SAFETY' FOR REAR SPAR TAKEN AS ·75 THAT FOR FRONT SPAR.
MEAN DEPTH OF SPAR TAKEN AS, [(THICKNESS OF SECTION ON SPAR CENTRE) — ·1(MAXIMUM THICKNESS OF SECTION)].
SPARS TAKEN AS OF 'STANDARD' FORM OF CROSS SECTION.
TOTAL SPAR WEIGHTS, (WF + WR).
REAR SPAR WEIGHTS, (WR)
FRONT SPAR WEIGHTS, (WF).
CURVES DRAWN IN DIFFERENT TYPES OF LINE THUS:-
FOR FRONT SPAR CENTRE AT ·16 CHORD FROM L.E.
" " " " " ·14 " " "
" " " " " ·12 " " "
" " " " " ·10 " " "
" " " " " ·08 " " "
" " " " " ·06 " " "
·42 ·44 ·50 ·54 ·58 ·62 ·66 ·70 ·74 CHORD.
SCALE OF DISTANCE OF CENTRE OF REAR SPAR FROM L.E.



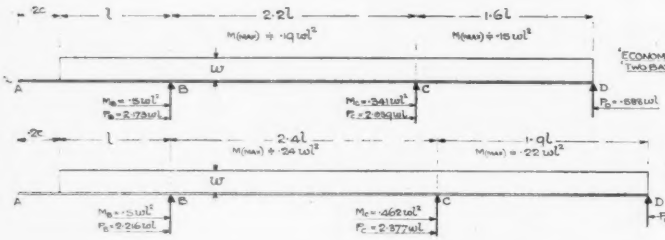
AREA BELOW CURVE A–B = ·778 UNITS²
" OF EQUIVALENT RECTANGLE = ·800 UNITS²

MOMENT OF AREA BELOW CURVE, ABOUT BC = ·313 UNITS³
MOMENT OF AREA OF EQUIV. RECTANGLE " = ·320 UNITS³

LOAD GRADING AT WING TIP.

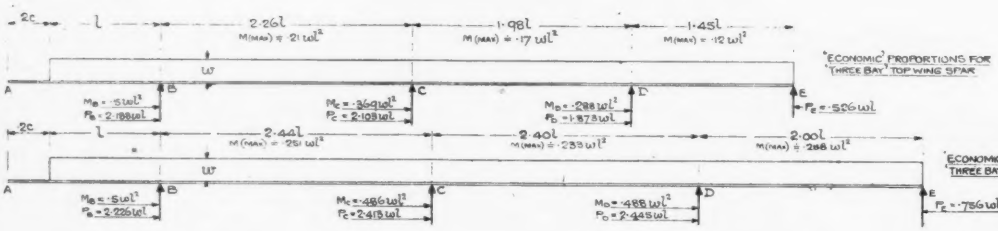


'ECONOMIC' PROPORTIONS FOR 'SINGLE BAY' WING SPAR. (TOP & BOTTOM WING.)



'ECONOMIC' PROPORTIONS FOR 'TWO BAY' TOP WING SPAR.

'ECONOMIC' PROPORTIONS FOR 'TWO BAY' BOTTOM WING SPAR.

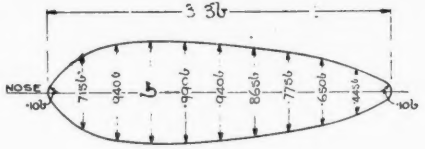


'ECONOMIC' PROPORTIONS FOR 'THREE BAY' TOP WING SPAR.

'ECONOMIC' PROPORTIONS FOR 'THREE BAY' BOTTOM WING SPAR.

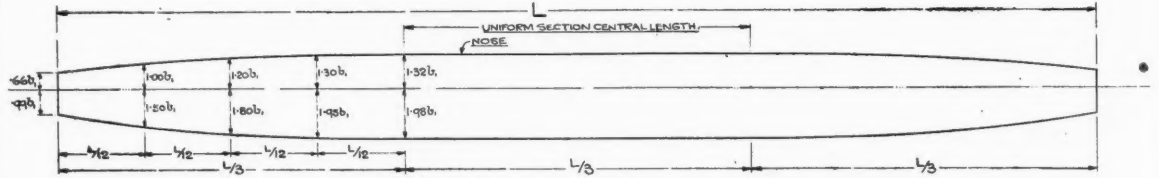
PLATE IV

19



$$\begin{cases} A = 2{\cdot}47\,b^2 \\ I = {\cdot}15\,b^4 \\ k = {\cdot}246\,b \end{cases}$$

PROPORTIONS FOR ALL CROSS SECTIONS



PROPORTIONS FOR STANDARD STRUT.

TAKING L & b IN INCHES & DENSITY OF WOOD AS 32 lbs/c.f. ..... $W = {\cdot}0384\,Lb^2$ lbs. (1)

TAKING CRIPPLING LOAD, $P = {\cdot}8\frac{\pi^2 E I}{L^2}$ & $E = 1{\cdot}5\times10^6$ lbs/□" ..... $P = \frac{1800000\,b^4}{L^2}$ lbs. (2)

HENCE, FROM (1) & (2) ..... $W = {\cdot}0000286\,L^2\sqrt{P}$ (3)

NOTE:- THESE VALUES FOR P HOLD WHEN $L/k > 110$, i.e. WHEN $L/b > 27$

HEAD RESISTANCE AT V FEET PER SEC.,

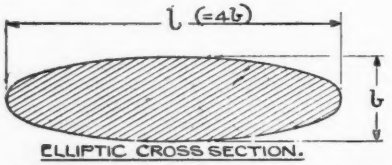
$R = k_1 v^2 L b$

$= k_2 v^2 \sqrt{LW}$

$= \frac{64}{15} v^2 \sqrt{LW}$ lbs (4)

PLATE V

FIGS. FOR 'RAF' WIRES.



ELLIPTIC CROSS SECTION.

If l & b IN INCHES & DENSITY = ·284 lbs/CU. INS. :-

$\Omega = \cdot 7854\, l b = 3 \cdot 1416\, b^2$ IN SQ. INS.

W = WGT IN LBS PER FOOT RUN $= 10 \cdot 7\, b^2$ ..... (i)

If P, ULTIMATE TENSILE STRENGTH, = 45 TONS/SQ. INS., THEN ULTIMATE BREAKING LOAD $P = 317000\, b^2$ LBS ..... (ii)

FROM (i) & (ii) $W \div \frac{\cdot 34}{10^4} P$ ..... (iii)

HEAD RESISTANCE AT v FEET PER SEC.,

$R = k_1 v^2 b L$ WHERE L = LENGTH OF WIRE IN FEET.

$= k_2 v^2 \sqrt{P}\, L$

FROM N.P.L. FIGS. $k_2 \div 7/10^3$

OR $R \div \frac{7}{10^3} v^2 \sqrt{P}\, L$ IN LBS. ..... (iv)

W_e = WGT IN LBS OF END FITTINGS (i.e. 2 FORK JOINTS, WITH PINS, SPLIT PINS & LOCK NUTS) $= \frac{\cdot 52}{10^4} P$ PER WIRE (v)

PLATE VI

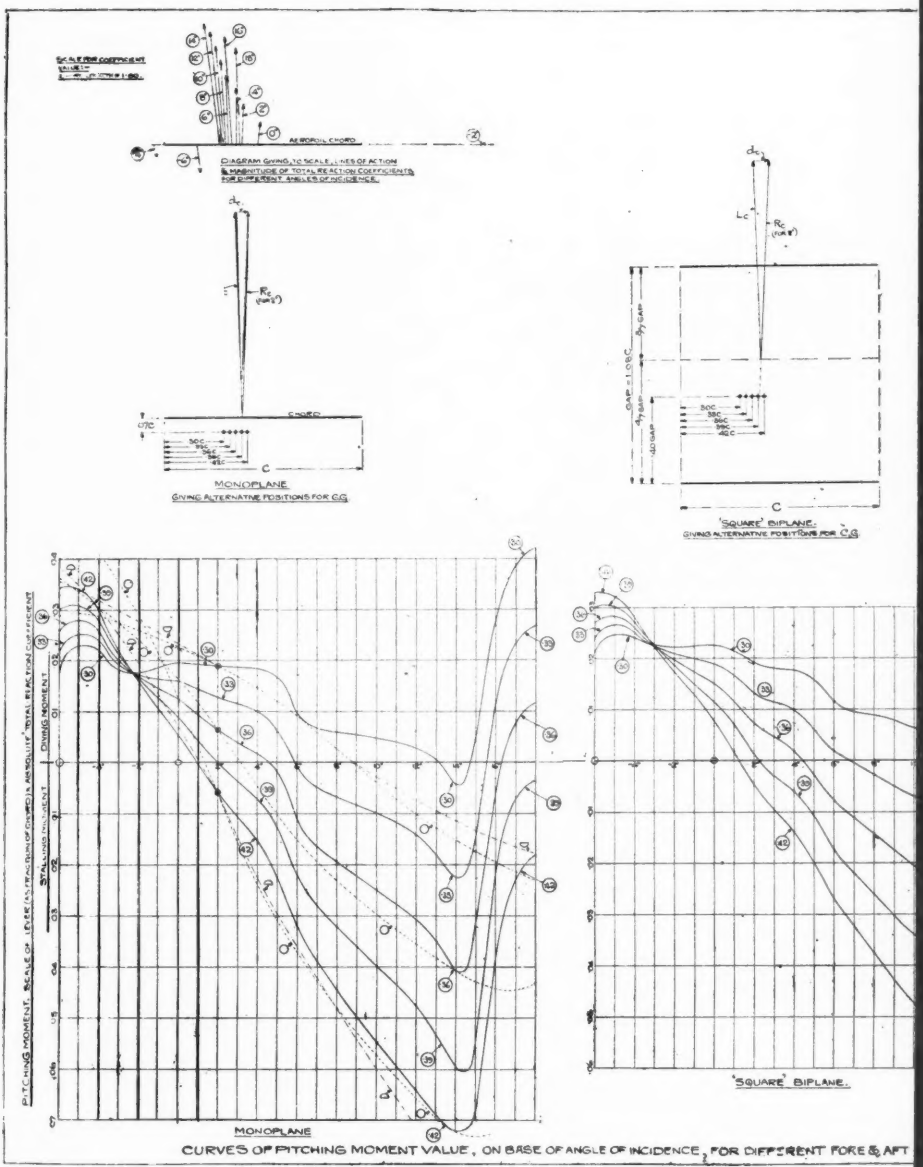
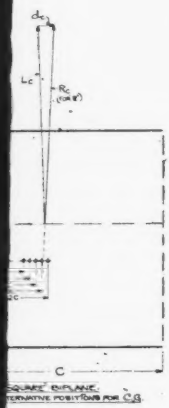
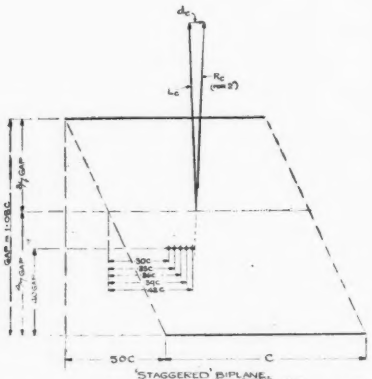


DIAGRAM GIVING TO SCALE LINES OF ACTION & MAGNITUDE OF TOTAL REACTION COEFFICIENTS FOR DIFFERENT ANGLES OF INCIDENCE.
AEROFOIL CHORD
MONOPLANE
GIVING ALTERNATIVE POSITIONS FOR C.G.
'SQUARE' BIPLANE.
GIVING ALTERNATIVE POSITIONS FOR C.G.
PITCHING MOMENT. SCALE OF LEVER ARM FRACTIONS OF CHORD (+ ABSOLUTE) TOTAL REACTION COEFFICIENT
30° ALLOWED INCIDENCE
DIVING MOMENT
MONOPLANE
'SQUARE' BIPLANE.

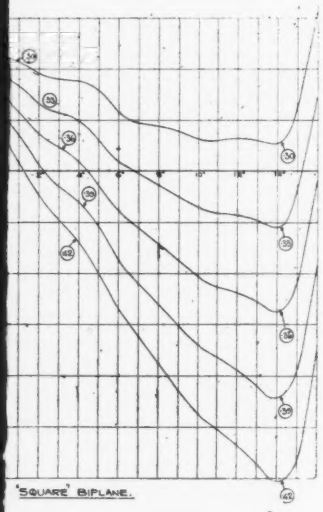
CURVES OF PITCHING MOMENT VALUE, ON BASE OF ANGLE OF INCIDENCE, FOR DIFFERENT FORE & AFT



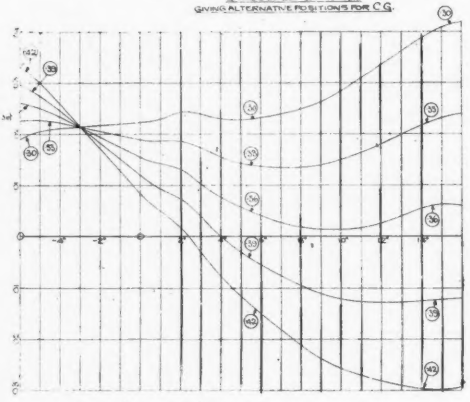
'SQUARE' BIPLANE.
ALTERNATIVE POSITIONS FOR C.G.



'STAGGERED' BIPLANE.
GIVING ALTERNATIVE POSITIONS FOR C.G.



'SQUARE' BIPLANE.



'STAGGERED' BIPLANE.

FOR DIFFERENT FORE & AFT POSITIONS OF C.G.

PLATE VII

LATE VII

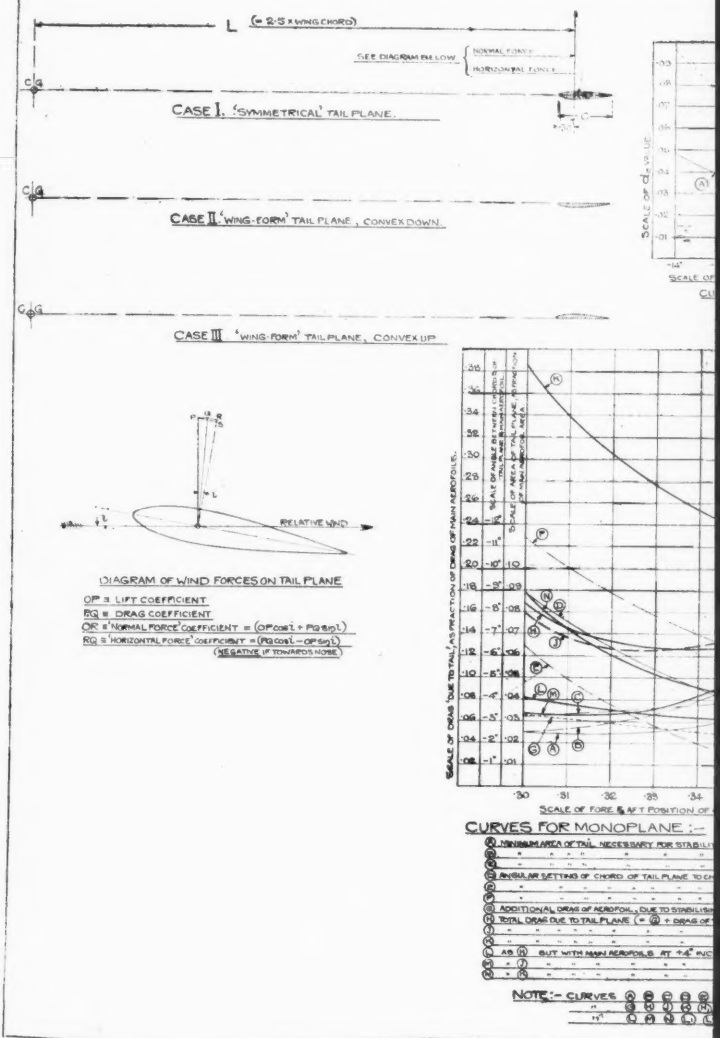

L (= 2·5 x WING CHORD)
SEE DIAGRAM BELOW
NORMAL FORCE
HORIZONTAL FORCE
C/G
CASE I. 'SYMMETRICAL' TAIL PLANE.
CASE II. 'WING-FORM' TAIL PLANE, CONVEX DOWN.
CASE III 'WING-FORM' TAIL PLANE, CONVEX UP
RELATIVE WIND
SCALE OF C_L VALUE
SCALE OF
SCALE OF DRAG DUE TO TAIL AS FRACTION OF DRAG OF MAIN AEROFOILS.
SCALE OF ANGLE BETWEEN CHORD OF TAIL PLANE & DIRECTION OF RELATIVE WIND
SCALE OF ANGLE OF TAIL PLANE SURFACE TO FUSELAGE DATUM
SCALE OF FORE & AFT POSITION OF
CURVES FOR MONOPLANE :-
NOTE :- CURVES

DIAGRAM OF WIND FORCES ON TAIL PLANE

OP = LIFT COEFFICIENT

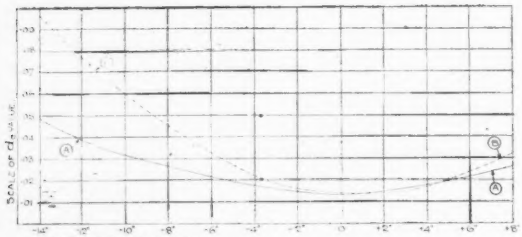
RQ = DRAG COEFFICIENT

OR = 'NORMAL FORCE' COEFFICIENT = $(OP\cos i + PQ\sin i)$

RQ = 'HORIZONTAL FORCE' COEFFICIENT = $(PQ\cos i - OP\sin i)$

(NEGATIVE IF TOWARDS NOSE)

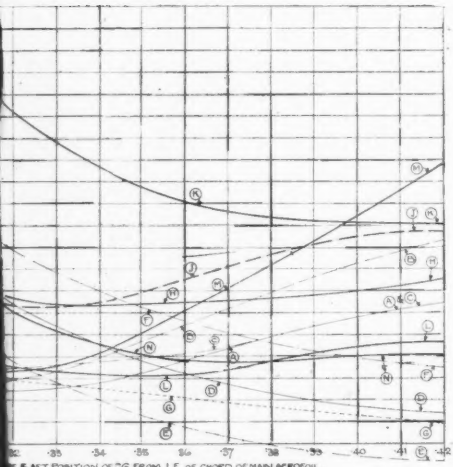
PLATE VIII



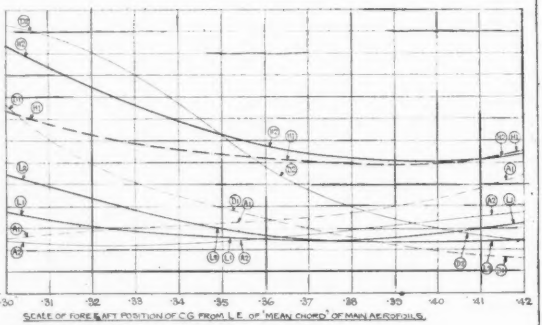
SCALE OF INCIDENCE OF TAIL PLANE.

CURVES OF 'ABSOLUTE' DRAG COEFFICIENT, C_{D_T}, ON A BASE OF ANGLE OF INCIDENCE

FOR:- (A) 'SYMMETRICAL' TAIL PLANE.
(B) 'WING FORM' TAIL PLANE.



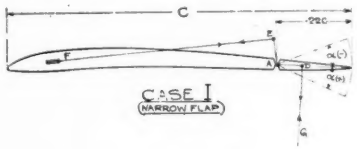
SCALE OF FORE & AFT POSITION OF CG FROM L.E. OF CHORD OF MAIN AEROFOIL.



SCALE OF FORE & AFT POSITION OF C.G. FROM L.E. OF 'MEAN CHORD' OF MAIN AEROFOILS.

NOPLANE :-

CESSARY FOR STABILITY, 'SYMMETRICAL' FORM.
" " " 'WINGS-FORM' CONVEX DOWN.
" " " UP.
ORD OF TAIL PLANE TO CHORD OF AEROFOIL, 'SYMMETRICAL' TAIL.
" " " " 'WINGS-FORM' CONVEX DOWN.
" " " " UP.
OFOIL, DUE TO STABILISING DOWN LOAD ON TAIL, AS FRACTION OF ORIGINAL AEROFOIL DRAG.
LANE (= (C) + DRAG OF TAIL PLANE) AS FRACTION OF ORIGINAL AEROFOIL DRAG, FOR 'SYMMETRICAL' TAIL.
" " " "



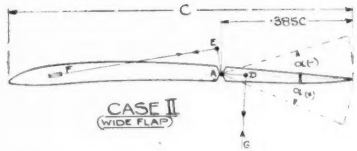
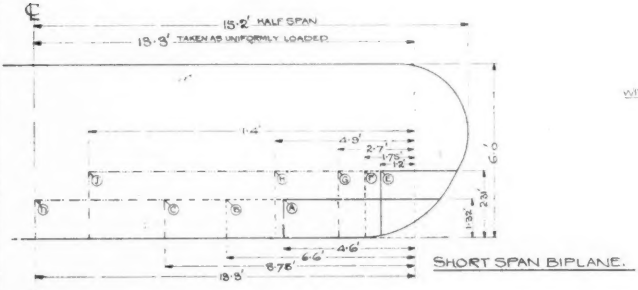


TABLE OF FLAP VALUES. (FOR 16'×2'8" MODEL AT 4
FLAP = ·385C (CASE II).

α	Lc	ADDED Lc	M	l	t	l/t	α	f
+30°	·669	+·097	-·030	+·138	-·709	-·195	±30°	·07
+20°	·711	+·145	-·0096	+·206	-·523	-·394	±20°	·09
+15°	·710	+·144	-·0082	+·205	-·447	-·459	±15°	·78
+10°	·695	+·129	-·0063	+·184	-·343	-·536	±10°	·56
+5°	·640	+·074	-·0049	+·105	-·267	-·393	± 5°	·30
+2·5°	·606	+·040	-·0048	+·057	-·227	-·251	±2·5°	·16
0	·566	—	-·0054	—	-·185	—		
-2·5°	·492	-·074	-·0027	-·105	-·147	+·715		
-5°	·428	-·138	-·0019	-·196	-·104	+1·88		
-10°	·296	-·270	—	-·384	·000	∞		
-15°	·160	-·406	+·0016	-·577	+·067	-6·63		
-20°	·035	-·531	+·0036	-·755	+·196	-3·85		
-30°	·024	-·590	+·0070	-·840	+·382	-2·20		

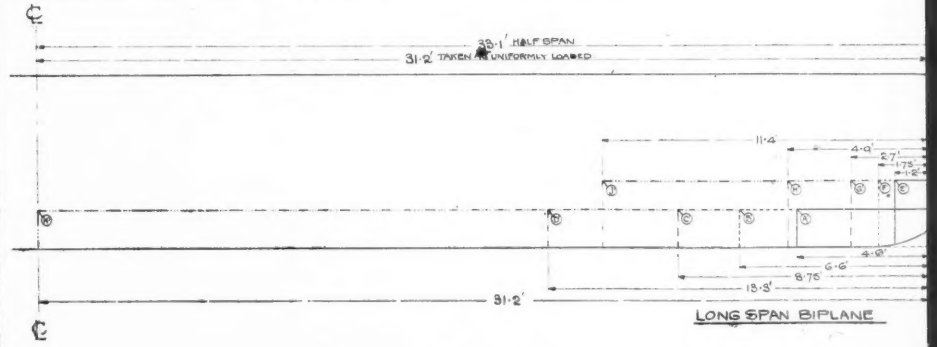
WHERE
M = MOMENT OF FORCE ON FLAP, ABOUT HINGE A, IN F
L = ADDED LIFT IN LBS. = ADDED Lc × 1·422
T = TENSION IN LBS. IN CONTROL WIRE (DG OR EF) = M ÷
+T IS +VE TENSION IN EF
-VE DG
F = SUM, IN LBS. OF UP & DOWN FORCES.
R = RESULTANT TENSION IN CONTROL WIRE, IN LBS.

FOR BOTH CASES:- AD = AE = ·0733 C
HK = ·4C
MAXIMUM LATERAL ANGULAR MOVEMENT OF HK = 15° EACH SIDE OF VERTICAL
MAXIMUM APPLIED LATERAL FORCE AT K = 50 LBS
HJ IS ADJUSTABLE, TO ATTAIN ANY PARTICULAR VALUE FOR Q,
MAXIMUM UP & DOWN ANGULAR MOVEMENT OF FLAP.



SHORT SPAN BIPLANE.

WITH 50 lbs APPLIED AT K, V = 72·2 FPS & L = +12
A E A' E' ARE FLAPS WHICH PULL TO 30
B F B' F' " " " " " 25
C G C' G' " " " " " 20
D H D' H' " " " " " 15
J K' J' " " " " " 10



LONG SPAN BIPLANE

TABLE OF FLAP VALUES. (FOR 18"×3" MODEL AT 40 FPS)

FLAP = "ABSC (CASE II).

α	Lc	ADDED Lc	M	l	t	l/t	α	f	p	f/p	
+30°	·665	+·097	·0130	+·138	·709	·195	±30°	·978	1·091	·895	
+20°	·711	+·145	·0096	+·206	·523	·394	±20°	·961	·719	1·34	
+15°	·710	+·144	·0082	+·205	·447	·459	±15°	·782	·534	1·46	
+10°	·695	+·129	·0063	+·184	·343	·536	±10°	·568	·343	1·65	
+5°	·640	+·074	·0049	+·105	·267	·393	±5°	·301	·164	1·83	
+2·5°	·606	+·040	·0042	+·057	·227	·251	±2·5°	·162	·080	2·02	
0	·566	—	·0034	—	·185	—					
-2·5°	·492	-·074	·0027	-·108	·147	-·715					
-5°	·428	-·138	·0019	-·196	·104	-1·88					
-10°	·296	-·270	—	-·364	·000	∞					
-15°	·160	-·406	-·0016	-·577	-·087	6·63					
-20°	·035	-·531	-·0036	-·755	-·196	3·85					
-30°	·024	-·540	-·0070	-·840	-·382	2·20					

↑ FOR AEROFOIL = +12°

WHERE

M = MOMENT OF FORCE ON FLAP, ABOUT HINGE A, IN FT-LBS

l = ADDED LIFT IN LBS. = ADDED L_c × 1·422 } FOR SINGLE AEROFOIL OR FLAP

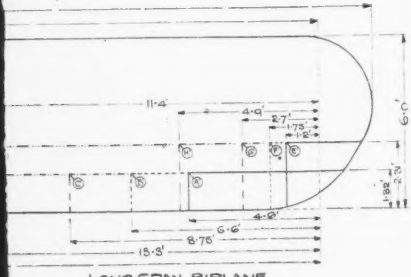
t = TENSION, IN LBS, IN CONTROL WIRE (DG OR EF) = M × 34·5
(+ IS +VE TENSION IN EF, − IS +VE TENSION IN DG)

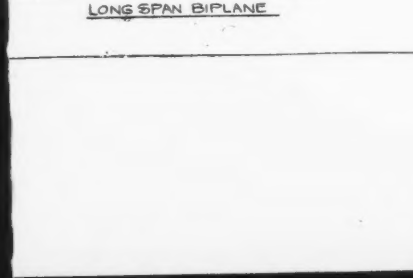
f = SUM, IN LBS, OF UP & DOWN FORCES } FOR TWO AEROFOILS, ONE WITH UP AND OTHER " DOWN

p = RESULTANT TENSION IN CONTROL WIRE, IN LBS

WITH 50 LBS APPLIED AT K, V = 72·2 FPS & i = +12°:-

A	E	A'	E'	ARE FLAPS WHICH PULL TO	30°	± OL VALUE.
B	F	B'	F'	" " " " "	25°	" "
C	G	C'	G'	" " " " "	20°	" "
D	H	D'	H'	" " " " "	15°	" "
J	K	J'	K'	" " " " "	10°	" "





LONG SPAN BIPLANE

EQUATIONS:-

FOR FULL SIZE WING OF 6·0' CHORD, TA
& THEREF

FOR FLAP RANGE OF +α 12 −α, $\frac{M}{AD}$ =
SO MAXIMUM APPLIED LOAD IN CONTROL WI

IF Y = LENGTH OF EACH OF FOUR EQUAL F
SUM OF UP & DOWN FORCES ON WIN
THIS RANGE OF FLAP MOVEMENT O

$= \frac{f}{L} \times \frac{S}{35} \times \frac{4\cdot4}{3\cdot0}$

$= \frac{4080}{C^2} \times \frac{f}{P_{40}}$ (

SIMILARLY FOR FULL SIZE WINGS, A

CURVES FOR FLAP VALUES F
ASSUMING FORCE OF 50 LB

F = RESULTANT TENSION APPL
FN = SUM OF UP & DOWN FORC
FK = " " " " "
LN = REQUIRED LENGTH FOR
LN = " " " "
RMINS12 = ROLLING MOMENT O
RMWS12 = " "
RMINL12 = " "
RMWL12 = " "
RMINLO = " "
RMWLO = " "

* WHEN V = 72·2 FPS.
** " i = 160

QUATIONS:-

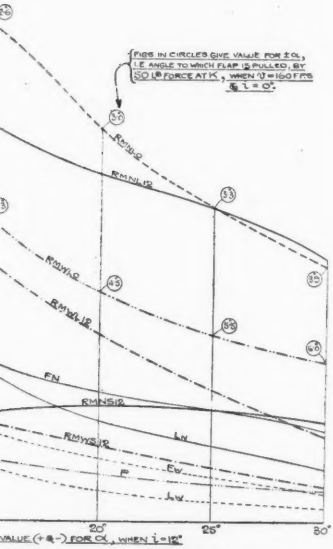
IS OF 6-0" CHORD, TAKING $V = 160$ FPS WHEN $i = 0°$.
& THEREFORE $V = 78{\cdot}2$ " " " $= +12°$

$+\alpha$ TO $-\alpha$, $HJ/AD = \alpha°/15°$, OR $HJ = 44\frac{\alpha°}{15°}$ IN FEET.
APPLIED LOAD IN CONTROL WIRES $= 50 \times \frac{HJ}{17} = \frac{4080}{\alpha°}$ IN LBS $= P_n$ (i)

EACH OF FOUR EQUAL FLAPS OF A BIPLANE, IN FEET:-
& DOWN FORCES ON WINGS, AT 72·2 FPS ($i = +12°$), FOR
E OF FLAP MOVEMENT OF $+\alpha$ TO $-\alpha$.

$$= f_n \times \frac{6}{2\cdot5} \times \frac{4\cdot4}{3\cdot0} \times \frac{72\cdot2^2}{40^2} \Bigg\} \text{WHENCE } y = \frac{39\cdot1}{R_n \times \alpha^2} \text{ IN FEET. (iii)}$$
$$= \frac{4080}{\alpha^2} \times \frac{f_n}{R_n} \text{ (ii)}$$

FOR FULL SIZE WINGS, AT 150 FPS ($i = 0°$) $y = \frac{7\cdot96}{R_n \times \alpha^2}$ IN FEET. (iv)



VALUE (+ & −) FOR α, WHEN $i = 12°$

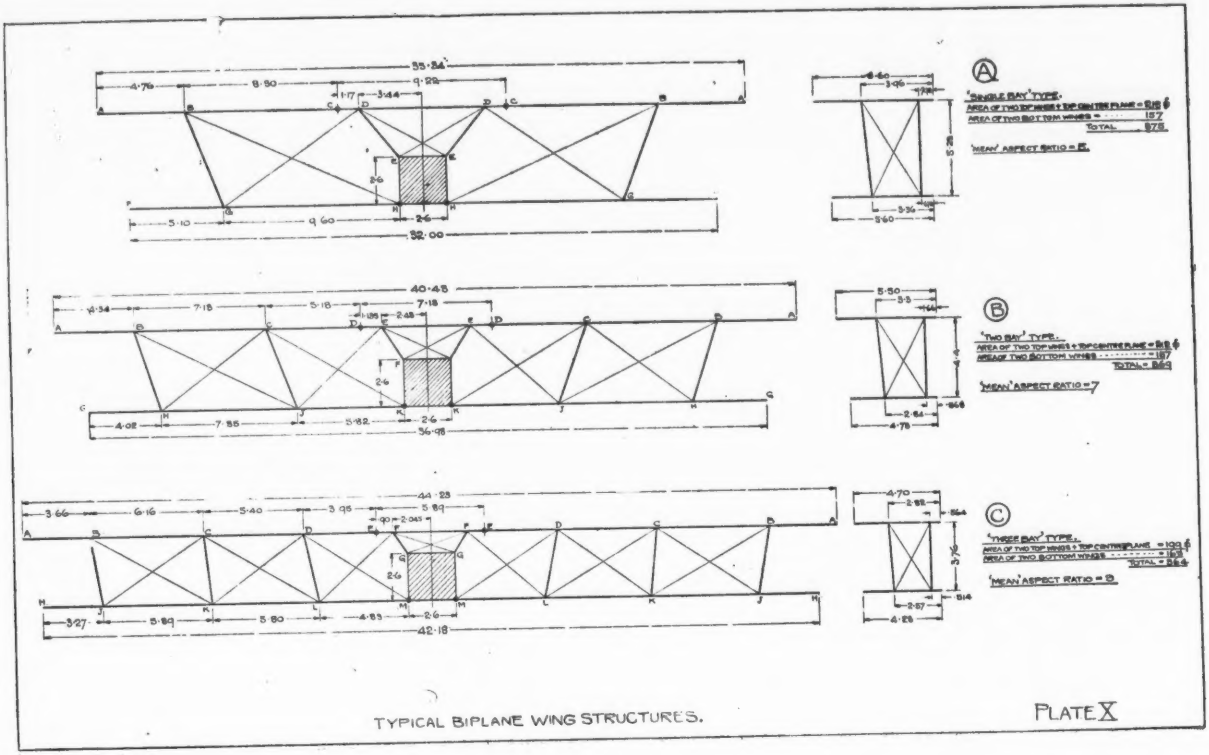
AP VALUES FOR BIPLANE OF 6' CHORD,
ORCE OF 50 LBS APPLIED AT K BY PILOT:-

ANT TENSION APPLIED TO CONTROL WIRES.
UP & DOWN FORCES, FOR NARROW FLAPS. *
" " " " WIDE " " *
RED LENGTH FOR EACH OF FOUR NARROW FLAPS. *
" " " " WIDE " " *
ROLLING MOMENT ON SHORT SPAN BIPLANE WITH NARROW FLAPS. *

"	"	"	"	"	"	WIDE	" *
"	"	"	LONG	"	"	NARROW	" *
"	"	"	"	"	"	WIDE	" *
"	"	"	"	"	"	NARROW	" *
"	"	"	"	"	"	WIDE	" *

$V = 72{\cdot}2$ FPS AND $i = +12°$
$= 160$ " " $= 0°$

PLATE IX



TYPICAL BIPLANE WING STRUCTURES.

PLATE X

values will alter in exactly the same proportions for the full sized machines as they do for models, and I have used model figures given by the N.P.L.

On these assumptions:—

(C_1) may be loaded to 7.58lbs. per sq. ft., meaning 2,760lbs. total weight for its 364 sq. ft. of wing area.

(C_2) may be loaded to 7.73, meaning 2,810lbs. total weight.

(C_3) may be loaded to 7.86, meaning 2,860lbs. total weight.

This means of course that (C_1) will carry 50+30=80 galls. petrol, (C_2) will carry 50+34=84 galls., and (C_3) 50+37=37 galls.

Using the same methods of calculation as for Cases (A), (B) and (C), the following figures are obtained:—

	Case (C_1).	Case (C_2).	Case (C_3).
Initial climbing rate	1600	1560	1520 ft. per min.
Cruising duration at 90 m.p.h. ...	6.6	6.8	6.9 hours
,, ,, ,, ...	594	612	621 miles

I have not worked out the high speeds as they will certainly be slightly lower than for Case (C), nor the moments of inertia, as they will certainly be higher than for (C).

The weak points in these calculations are, firstly and mainly, that values for "absolute" lift coefficient and for "lift-over-drag" are taken from the curves of Plate 1, and the accuracy of these curves is distinctly questionable. Secondly, no allowances have been made for the "interference" effects of the different parts of the wing structure upon one another; probably Cases (B) and (C) would be of slightly greater head resistance compared to Case (A) than is given, if "interference" were taken into account. Thirdly, no allowances have been made for propeller slip-stream effect on head resistance, and it is probable that this would have different comparative effects on the different types.

Taking the results for what they are worth, however, it would appear that for manœuvrability certainly and speed probably the shortish span machine has the advantage, whilst for climb, weight lifting and range, the machine of high aspect ratio is very distinctly superior. The speeds, however, are rather remarkably alike and the climbs of comparatively small differences; the greatest differences are superiority of duration at cruising speed for the long span machine. Generalising, one might say that a smallish fighting or acrobatic machine should be of a fairly low aspect ratio; machines which are solely to carry bombs, passengers, or cargo, should certainly be of high aspect ratio and of good gap value.

I trust that the few cases I have dealt with, and at that sketchily, will serve at least one purpose—to emphasise that a vast amount of work may be put most usefully into research as to economic conditions, for of all engineering structures the aeroplane is that one on which we can least afford to waste any weight or efficiency.

FROM MODEL TO FULL SCALE IN AERONAUTICS.

BY H. LEVY, M.A., D.SC., F.R.S.E.

LADIES AND GENTLEMEN,

At frequent intervals in the past the subject of the passage from model to full scale has received fairly thorough treatment at the hands of the members of this Society, and although a considerable mass of further material of extreme practical importance has since then accumulated, I do not propose to present it to you this evening. Those who are particularly interested in the data will find the greater part of it discussed in the Reports and Memoranda of the Advisory Committee for Aeronautics. I intend instead to devote this evening to a study of the question from a more theoretical standpoint, and in doing so I make no apology. Now that we have passed out of the strain of doing into the peace of done, when the compulsion of immediate practical application is no longer necessary, we cannot afford to delay the study of the theory and theoretical interpretation of what has become familiar and commonplace in practice.

In aeronautics, experimental research by means of models is particularly suitable on account of the control that can be exercised over the experimental conditions as compared with attempts of the same nature on the full scale machine. The greater number of the troubles that arise in the latter case, such as those due to wind currents, uncertain meteorological conditions, etc., find no counterpart in wind channel research, while the actual measurement of the forces and moments brought into play has been reduced to a fine art. Such a high degree of accuracy, however, is futile, unless the laws of transition from the model to the full scale are known and can be applied with corresponding precision.

The problem we have to face may be stated thus:—A flying machine, or part of one, is in motion through the air with a given speed in the region of the normal speed of flight, is there a corresponding experiment on a model from which the forces originated on the full scale may be deduced?

It will become clear that fundamentally there can only be one complete and satisfactory answer to this question. It is implied in the more general problem—a body of given size and shape is in motion with a given speed in a medium of known properties, what are the forces brought into play? The former question if answered merely connects up two problems as being physically identical, whereas the latter question if answered not merely includes the former but provides the actual forces. A complete solution in fact would practically eliminate the necessity for further aerodynamic experiments. The obstacles that have to be surmounted by facing the question from each of these standpoints will become evident as the discussion proceeds.

To give more definiteness to the problem, consider the properties of the medium—air—with which we have to deal. Its constitution is molecular, and such that any gradient in velocity is accompanied by a viscous dragging force; it has density; it is compressible. These are the only properties with which we are concerned, but they are not all three equally important in determining the forces originated. It will be seen, for example, that for most aerodynamic problems that arise in practice, compressibility plays a comparatively negligible part, and that to all intents and purposes air may be regarded as incompressible. The evidence upon which this conclusion is based is principally of an experimental nature, but the following simple analysis gives some indication of the probable effect of compressibility.

Let us assume the fluid elastic but non-viscous and attempt to compute the effect of elasticity on the pressure existing at the nose of a body in the moving fluid. It is generally found experimentally that the pressure is a maximum at this point. If p_0 and v are the pressure and velocity at a great distance from the body, and p the pressure at the nose, then assuming the expansions and contractions of the medium so rapid that the process takes place adiabatically

$$p/p_0 = (\rho/\rho_0)^{\gamma}$$

where γ is the ratio of the specific heats.

Moreover

$$\rho_0 V^2 = E = \gamma p_0$$

where V = velocity of sound in the medium, and E = compressibility. Bernoulli's equation for such a fluid is

$$v^2/2 + \int_{\rho_0}^{\rho} \frac{dp}{\rho} = v_0^2/2 = 0 \text{ at the nose.}$$

$$\therefore (p/p_0)^{(\gamma-1)/\gamma} = 1 + \frac{\gamma-1}{2} \cdot \frac{v^2}{V^2}$$

$$\therefore p - p_0 = \tfrac{1}{2}\rho_0 v^2 \left[1 + v^2/4V^2 \ . \ . \ .\right]$$

It follows that $p - p_0$ the maximum dynamic pressure is sufficiently represented by the first term of this expression, viz., $\frac{1}{2}\rho_0 v^2$, as long as $v^2/4V^2$ is negligible compared with unity. An error of the order of 1 per cent. will thus creep in by the assumption that the gas is incompressible as soon as v becomes of the order

$$v = .2V = 220 \text{ ft./sec.} = 150 \text{ mls./hour,}$$

and this is approximately the maximum speed attainable by the swiftest aeroplanes at the present time.

It is to be anticipated then that for all parts of an aeroplane or airship in contact with the air—to the exclusion for the moment of the propeller—the resistance coefficient will not be affected to any measurable extent in general by the fact that the air is a compressible medium. This anticipated result is borne out by the following curve obtained by an analysis of the motion of projectiles, from which it is apparent that the resistance coefficient of a shell is scarcely affected with increase of speed until the velocity approaches that of sound, when a considerable quantity of energy is expended in the production of compression waves.

The medium with which we have to deal may therefore be defined by its density ρ and its viscosity ν while we assume it incompressible.

The viscous forces are originated by the interaction of any two contiguous layers of the fluid, but since the problem in general deals with the motion of a solid body in such a medium the latter will not be completely defined until the boundary conditions—the nature of the interaction between the solid and the fluid are clearly given.

Attempts made at the N.P.L. and elsewhere to measure the surface velocity of air flowing past a solid body have not yet led to perfectly conclusive results, principally on account of the fact that in very close proximity to the body the velocity begins to fall with great rapidity. Whatever results have so far been obtained are, however, not inconsistent with the assumption that the relative velocity at the surface is zero. In the case of water, a fluid practically incom-

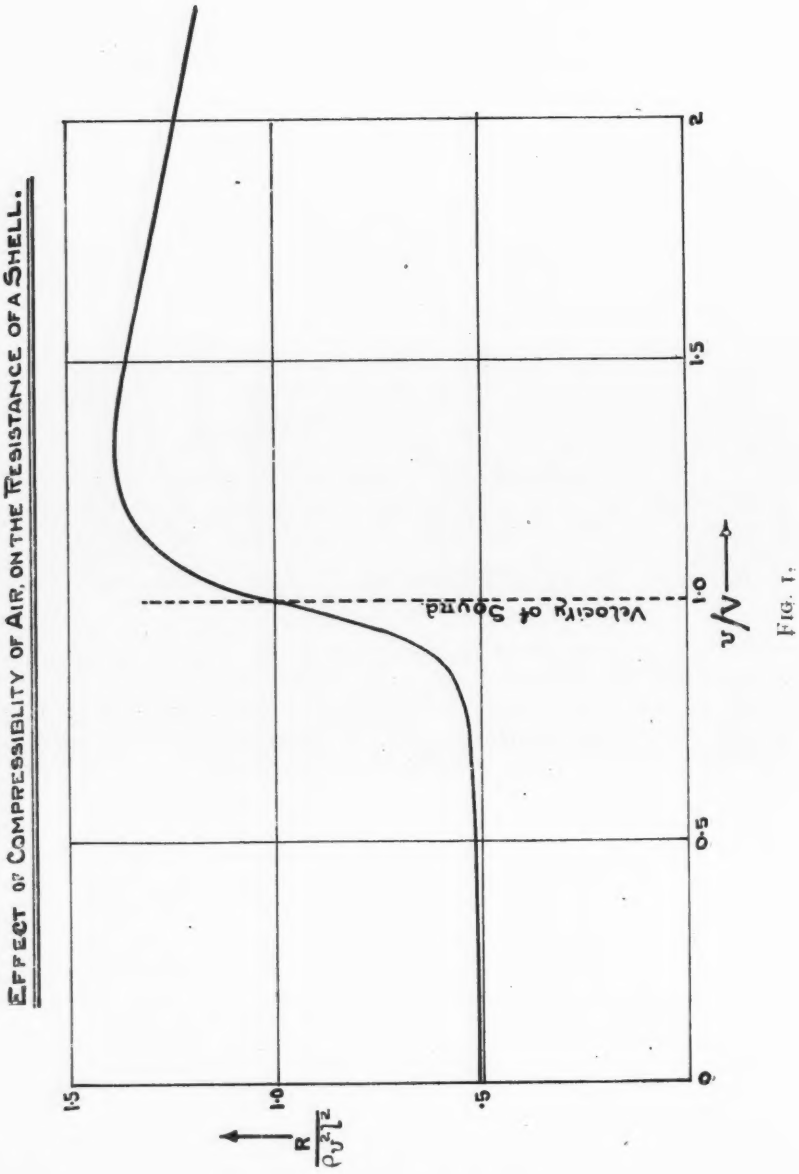

EFFECT OF COMPRESSIBILITY OF AIR, ON THE RESISTANCE OF A SHELL.
Velocity of Sound
V/A
R/ρV²Z
0
.5
1.0
1.5
2

FIG. 1.

pressible and likewise defined, as far as we are at present concerned, by its density and viscosity, the evidence is much more definite. The annexed figure gives one of a collection of photographs taken at the N.P.L. of the flow past a thin plate, the length of each dash being very approximately proportional to the velocity at the mean point. When a system of velocity curves over the whole field is drawn, the boundary of the plate coincides as accurately as can be judged with the curve of zero velocity. The rapidity with which the velocity diminishes close to the body is evident from the smallness of the dashes in that region.

In effect the conclusion is equivalent to the statement that there is a continuous distribution in velocity from the interior of the body to the interior of the fluid.

Summing up then, we assume that the medium is defined by its density ρ, its viscosity ν, by the assumption that it is incompressible and by the statement that there is no relative motion between the fluid at the surface of the body and the body itself.

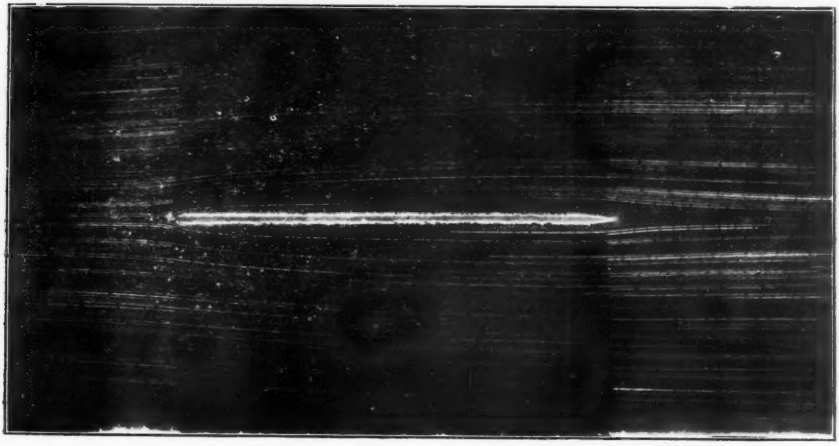


FIG. 2.

As far as we can judge at present these appear to be the only properties with which we are concerned, but should it be proved impossible at any future date to express all the phenomena that arise in terms of these, it may be necessary to extend them.

The two aspects of the problem—linking up or solving problems connected with models or with full scale—can now readily be seen to resolve themselves into two distinct methods of treatment of the same problem, the one more detailed than the other. In both cases we apply the Newtonian Dynamical Laws, in the one case in a slightly more general form than in the other.

Suppose the body, of given shape, size given by l the length of one part, to be in motion with uniform velocity V, in a fluid of density ρ and kinematic viscosity ν, and consider the nature of the flow and streaming of the fluid at some point geometrically fixed with reference to the body. Although the motion of the body itself is steady it does not follow that the fluid flow is uniform—this depends on the stability of the flow. If v is the velocity of the fluid element at the point considered, it can only depend on V, ρ, ν, l, t the time at which the

motion is considered, and the shape of the body. If there are no other boundaries it can depend on nothing else. We may therefore write

$$v = F\ (V,\ \rho,\ \nu,\ l,\ t).$$

Applying the principle of Homogeneity of Dimensions, which I need not here elaborate, it is easily found that each term in the expansion of the function must be of the form

$$AV \left(\frac{Vl}{\nu}\right)^m \left(\frac{Vt}{l}\right)^n$$

where A, m and n are dependent only on the shape of the body. In effect this implies,

$$v = V\Sigma A \left(\frac{Vl}{\nu}\right)^m \left(\frac{Vt}{l}\right)^n$$

$$= Vf\left(\frac{Vl}{\nu}, \frac{Vt}{l}\right)$$

where the form of the function depends absolutely on the shape of the body.

In the same manner if θ be the direction of flow at the point

$$\theta = g\left(\frac{Vl}{\nu}, \frac{Vt}{l}\right)$$

These expressions have been obtained by a simple application of the principle of Homogeneity of Dimensions based on Newton's Second Law of Motion, and as such they embody very general statements as regards the nature of the motion. It will be readily seen in fact, that they connect up a series of problems as being physically identical and thus lay the foundations for an application of model experiments to full scale.

If now we can consider two bodies of different sizes but identical contour moving steadily through different fluids, say air and water, with different velocities we must have

$$\theta_1 = g\left(\frac{V_1 l_1}{\nu_1}, \frac{V_1 t_1}{l_1}\right) \text{ for air,}$$

$$\theta_2 = g\left(\frac{V_2 l_2}{\nu_2}, \frac{V_2 t_2}{l_2}\right) \text{ for water,}$$

the form of the function being the same for both.

If the dimensions l_1 and l_2 of the bodies, and the viscosities ν_1 and ν_2 be given, it follows that there are two corresponding speeds given by

$$\frac{V_1 l_1}{\nu_1} = \frac{V_2 l_2}{\nu_2}$$

and two corresponding times given by

$$\frac{V_1 t_1}{l_1} = \frac{V_2 t_2}{l_2}$$

for which $\theta_1 = \theta_2$.

That is to say, at corresponding times the direction of flow at all geometrically corresponding points will be identical. The various phases and pictures of the flow which occur in the case of the flow of air with all its turbulence and eddy-production will be identical with those taking place in water except that the rate at which these various processes occur will differ.

The two systems will be *dynamically similar.*

Two exceedingly important experimental conclusions follow from this. In the first place a complete justification now exists for studying the nature of the air flow by a corresponding experiment in the flow of water—the two problems have now been completely linked up. Accurate photographic means can readily be devised for the study of water flow, whereas experimental methods for the corresponding quantitative study of air present much greater difficulties.

In the second place, if we restrict ourselves to the one medium, air, so that

$$\nu_1 = \nu_2$$

the two systems of streamlines will be identical if, at corresponding times,

$$V_1 l_1 = V_2 l_2$$

Applying the method of Homogeneity of Dimensions once more to determine a general expression for the resistance, we easily find

$$R = \rho V^2 l^2 F \left(\frac{Vl}{\nu}, \frac{Vt}{l} \right)$$

where the form of the function depends entirely on the shape of the body.

For the two bodies under consideration therefore, both moving in air, the resistance at corresponding times under conditions of dynamical similarity where $V_1 l_1 = V_2 l_2$ are also equal.

This startling result, it might be supposed, would be immediately utilised by testing a model in the wind channel at the value of Vl equal to that of the full scale, but unfortunately certain practical difficulties are immediately confronted. A model is rarely greater than 1/15 full scale and consequently for the conditions to be satisfied the channel wind speed would require to be fifteen times the flying speed, say about 2,000 ft. per second. Apart from the fact that such a speed is practically unattainable in a wind channel, even if it could be realised, the comparison would no longer be legitimate since the initial assumption that energy is not lost in compressibility waves would now be violated. The methods that have been adopted experimentally, with considerable success, to overcome this difficulty are probably familiar to most of you, and I do not propose to discuss them here. Suffice for the moment to say that in general it consists in testing the model in the wind channel at increasing values of Vl until, if possible, the resistance coefficient becomes sensibly constant, when the value of the latter quantity at the full scale Vl is obtained by methods of extrapolation. It should be remarked that although the term Vt/l appears in the expression for the resistance, the fluctuations of the latter with time are so rapid that in the wind channel at uniform wind speed the force excited appears to be constant.

By an application of Newton's Law of Motion through the very general medium of the Dimensional Theory, we have succeeded in identifying a large class of problem of the steady motion of a body in a viscous fluid. But the forces brought into play during steady motion are not the only ones that require investigation in aeronautical work. Analysis of the stability of aircraft demands a knowledge of the forces originated when the machine is disturbed from its path of steady motion and accelerates or decelerates back to its original path. It demands in fact a knowledge of the effect of acceleration on the resistance components of the machine—a question of special importance in airship work.

A considerable degree of light may likewise be thrown on the question by an application of the foregoing methods.

Suppose the body—for example an airship—of given outline, and size determined by the length l, is in motion in a fluid of density ρ and viscosity ν, its velocity and acceleration at the moment under consideration being v and a respectively. Let the body be moving into otherwise undisturbed air so that we may assume very approximately that the motion of the air at any point geometrically fixed with reference to the body will depend, apart from the properties of the medium, on the velocity and acceleration of the body only.

If θ be the direction of motion of the air at the point in question, then

$$\theta = f(v, l, \nu, \rho, a)$$

where the form of f depends on the shape of the body. As before, applying the Dimensional Theory we easily find

$$\theta = F\left(\frac{vl}{\nu}, \frac{al}{v^2}\right)$$

which indicates by parity of reasoning that if vl/ν and al/v^2 be maintained constant in the model and full scale, the systems of streamlines will be identical. They will in fact possess dynamical similarity.

Under these conditions the expression for the resistance will then take the form

$$R = \rho v^2 l^2 f\left(\frac{vl}{\nu}, \frac{al}{v^2}\right)$$

or

$$r = f\left(\frac{vl}{\nu}, \frac{al}{v^2}\right)$$

where r is the resistance coefficient.

It follows at once that just as the resistance to a body of given shape moving uniformly with velocity v does not depend on the latter quantity but on the value of vl/ν, so if the body be moving with an acceleration a the resistance at any moment depends, in addition to the momentary value of vl/ν, also upon the quantity al/v^2. A complete picture of the dependence of resistance coefficient on acceleration and velocity would be given on a chart as follows:—

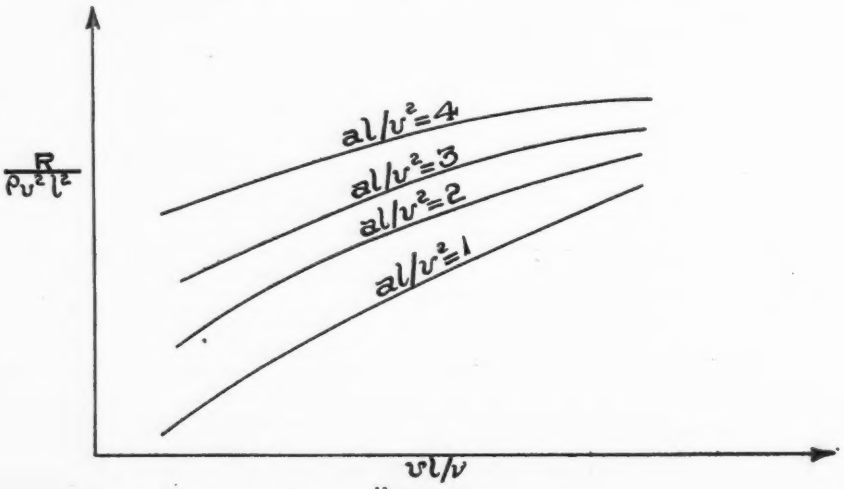


FIG. 3.

Once more it is possible to connect up an experiment on a model with the corresponding one on the full scale, but fortunately in this case the troubles that had to be confronted as regards the large value of vl required for the model does not arise with the acceleration term. It is evident, for example, that if the model properly weighted be allowed to fall freely in water until its terminal velocity is reached, v will be zero at the commencement of the drop, while a is finite, so that theoretically al/v^2 will be infinite, while when the terminal velocity is reached a is zero while v is finite, so that al/v^2 is zero. In one fall al/v^2 varies over the whole range from infinity to zero and there is no necessity for additional extrapolation. Experiments conducted at the N.P.L. along these and analogous lines have been most successful and have thrown an interesting light on the whole question.

From the foregoing analysis the laws of transition from the model to the full scale become quite clear, but it is equally apparent that it is not always practically possible to apply them. To every full scale experiment there corresponds one physically identical on a model, but the conditions thereby demanded cannot generally be completely realised. There is one aspect of the passage from model to full scale, however, which is generally accepted without question. If a series of aerodynamic models or bodies, for example, be tested in a wind channel, it is generally assumed that the particular one of minimum resistance, say among the set on the model scale, will likewise bear the same relation in this respect as far as order is concerned in the full scale. This is evidently not necessarily true *a priori*, and could only be justified by a knowledge of the actual law of variation of the forces right over the whole range. It is clear that even in this simple case a more accurate study of the laws of resistance on the theoretical side is urgently required if not actually to supplant model experimental work, at least to clarify many dubious points. But a study of the laws of resistance from this aspect involves, in effect, an investigation of the nature of the fluid flow past the body, for from a knowledge of this can be determined the rate at which energy is being dissipated through the fluid and hence also the resistance. This conception of the problem is of course much more general than that already outlined in the earlier parts of this paper and as such should embody the results previously obtained.

The equations of motion of a viscous incompressible fluid are unfortunately exceedingly complicated, and attempts so far to solve them have failure written all over them.

For two dimensions they become

$$\frac{\delta\zeta}{\delta t} = \nu\nabla^2\zeta - \left(u\frac{\delta\zeta}{\delta x} + v\frac{\delta\zeta}{\delta y}\right)$$

where 2ζ is the vorticity at any point, and is given by

$$2\zeta = \frac{\delta v}{\delta x} - \frac{\delta u}{\delta y} = \nabla^2\psi$$

The results previously obtained by application of the Dimensional Theory can, however, be derived at once from this equation by throwing it into a non-dimensional form. This can be done by writing

$$u = Vu' \qquad x = lx'$$

$$t = Tt'$$

$$v = Vv' \qquad y = ly'$$

when this equation becomes

$$\frac{l}{VT}\cdot\frac{\delta\zeta}{\delta t'} = \frac{\nu}{Vl}\cdot\nabla^2\zeta - \left(u'\frac{\delta\zeta}{\delta x'} + v'\frac{\delta\zeta}{\delta y'}\right)$$

from which it follows that everything that can be derived from this equation, all

the phenomena of the motion in fact will depend on the values given to the two non-dimensional quantities

$$\frac{VT}{l} \text{ and } \frac{Vl}{\nu}$$

the vital fact upon which the previous analysis hinged.

Although the equation thus contains the essence of what has gone before, it contains considerably more than this. For a differential equation of this type there usually exists special values of the constants for which the solution attains special or singular forms.

Physically this would imply that in the region of a particular value of vl/ν the state of fluid motion determined by this equation undergoes singular or critical changes. In actual fact Reynolds has already demonstrated by certain beautiful experiments that for the flow of water along circular pipes at a certain value of this quantity the flow changed abruptly from a steady continuous motion to one of violent turbulence and eddying. The phenomenon is likewise one of frequent occurrence in wind channel research where, in the neighbourhood of particular speeds, the forces excited undergo extremely rapid changes. It is moreover conceivable, although experimental evidence is not yet to hand to bear it out, that more than one such critical value of this quantity may exist.

There is evidently a wide field here for research, and a little successful analysis would probably throw a vivid light on what is, unfortunately, at present a series of very obscure phenomena. The whole problem of successful aerodynamic design —the laws determining the forces of resistance—will necessarily remain obscure until these matters have been cleared up.

Unfortunately past attempts to open up the question by direct frontal attacks on this formidable equation have, needless to say, been attempted with very indifferent success. The various modifications and simplifications introduced—so dear to the mathematician—have invariably resulted in excluding from the problem the very phenomena it is most vital to investigate. Steadiness and slowness of motion, inviscidness and irrotation in the fluid have all been considered, and have shed but little light on the real problems at issue as far as aerodynamical interpretation is concerned.

It has become increasingly clear in fact that the equation will not yield to a real frontal attack until the problem of offence has been more intensively studied and until mathematical physicists, expert in the use of their weapons, have concentrated upon it. The importance of solving these questions cannot be over emphasised, and those of us who have the development of the subject at heart would be only too grateful for assistance on these points.

A frontal attack being admittedly beyond our mathematical powers at the present moment, let us consider whether any flank movement is possible without involving restrictions that invalidate the aerodynamic application of the results.

Consider the following photograph of the flow past a plate.

FIG. 4.

In every case it appears that special centres of rotation concentrate in the fluid, and that the motion seems to be largely determined by the position and strengths of these eddies. For a real physical fluid the spin is naturally continuously disturbed over the whole medium, but the intensity becomes exceedingly acute at particular points. It is known that vorticity of this nature cannot be originated in an inviscid fluid except by the exertion of impulsive pressures or a non-potential external force. It follows that the eddying and the strength of the vorticity generally at each point of the fluid must be a direct result of the viscosity and of the boundary conditions.

If K be the total vorticity within a small circle surrounding any such centre of rotation, then the dimensions of K are L^2/T and since K will depend on ν, v and l the velocity and size of the body, and on its shape, applying the dimensional method as before, it is easily found that

$$K = \nu f\,(vl/\nu,\ vt/l)$$

where the form of the function depends only on the shape of the body. It is at once evident that for a series of problems in which vl/ν is maintained constant, that is to say, for a series of problems which possess dynamical similarity, the strength of the eddies set up is proportional to the degree of viscosity. If the one be given, it is equivalent to the other being given.

Does this mean that if we assume the fluid devoid of viscosity, imagine vortices of given strength, K, situated in the corresponding positions in this new medium, the motion will then be identical with that taking place in the viscous medium? The extent to which this is true can be seen at once by a consideration of the equations of motion.

Given the vorticity, the streamlines and all the circumstances of the motion are determined, both in the viscid and in the inviscid case, by the same equation, viz.,

$$\nabla^2\psi = 2\zeta$$

so that the instantaneous motion is the same in both cases, but the subsequent motion is bound to be different, for the expression giving the rate at which the vorticity changes, contains the term $\nu\nabla^2\zeta$, non-existent in the inviscid case. So much must be admitted; nevertheless, even to get the same instantaneous motion in the inviscid fluid with the mathematics of which we can deal, is worth having and worth studying. Let us assume then that the vortices are situated in given positions in the inviscid fluid and consider the direction of motion θ at any point of the fluid geometrically fixed with reference to the body. Then applying the same principles as before

$$\theta = F\,(vl/K)$$

and it follows that as long as vl/K is maintained constant from problem to problem, the systems of streamlines are geometrically identical and the problems are dynamically similar.

Two questions now present themselves. In the first place how is the intensity K of the eddy to be determined? It is clear from the preceding equations that although it is proportional to ν the coefficient of viscosity, the coefficient of proportionality is determined by the shape of the body. But if the image of the eddy be taken on the body, the latter removed, and the fluid assumed continuous everywhere, this is equivalent to saying it is determined by the arrangement of these eddies among themselves. If it be supposed the vortices will take up the position of stability, if such exists, it can be determined.

In the second place, if, as has been found experimentally, critical values of vl/ν exist for which the nature of the flow changes rapidly from one type to

another, and if our comparison is legitimate, a study in any particular problem of the type of flow for varying values of vl/K should also correspond to some break in type.

The second question will be considered first by means of an example since it will illustrate simultaneously certain mathematical methods of treatment of the first question. It should be remarked that the illustration does not pretend to correspond to the solution of any actual problem in a real fluid—certain boundary conditions will in fact be seen not to be completely satisfied—but it is sufficiently instructive I think to warrant consideration.

In the steady flow of a viscous fluid between the two walls of a channel the vorticity at each point is given by a linear function of the distance from the centre line. An identical distribution of velocity will be obtained by the same distribution of vorticity in a non-viscous fluid with the same boundaries. Suppose this be given, and in addition it be assumed that two vortices of strengths $+K$ and $-K$ be situated in the channel, evenly between the walls as in the diagram.

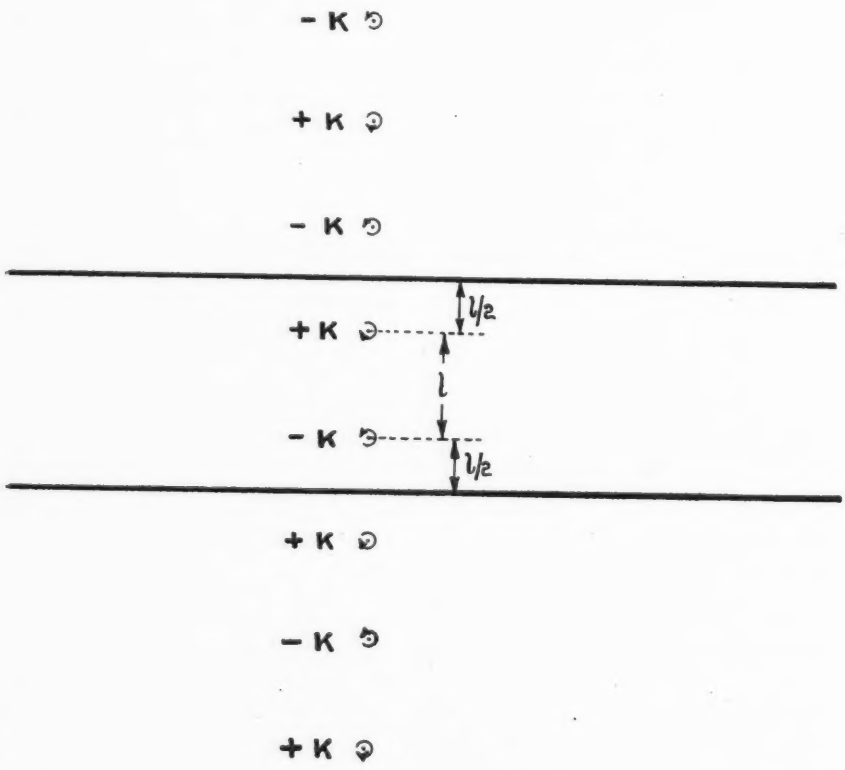


FIG. 5.

I am not, for the moment, concerned with the question of how the vortex pair originated. If the vortices be imaged in the walls of the channel, the problem as far as the two eddies are concerned may be replaced simply by an infinite system of vortices of alternating sign and strength K, as in Fig. 5.

The stream function due to such a system is given by

$$w = \frac{iK}{2\pi}[\log z + \log(z + 2li) + \log(z + 4li) + \ldots . + \log(z - 2li) + \log(z - 4li) + \ldots . - \log(z + li) - \log(z + 3li) - \ldots . - \log(z - li) - \log(z - 3li) - \ldots .]$$

$$= \frac{iK}{2\pi}\log\frac{z\,[z^2+(2l)^2]\,.\,[z^2+(4l)^2]\,\ldots .}{(z^2+l^2)\,[z^2+(3l)^2]\,\ldots .}$$

$$i.e.,\ \phi + i\psi = \frac{iK}{2\pi}\log\tanh\frac{\pi z}{2l}$$

Hence finally

$$\psi = \frac{K}{4\pi}\log\frac{\sin^2\pi y/2l + \sinh^2\pi x/2l}{\cos^2\pi y/2l + \sinh^2\pi x/2l}$$

The stream function calculated from the distribution of vorticity for steady viscous flow in the channel exclusive of the effects of the eddies is

$$\psi = u_0\,[(y - l/2)^3/3l^2 - (y - l/2)]$$

where u_0 is the velocity at the centre of the channel at an infinite distance.

This gives as the final stream function due both to the eddy pair and distribution of vorticity

$$\psi = \frac{K}{4\pi}\log\frac{\sin^2\pi y/2l + \sinh^2\pi x/2l}{\cos^2\pi y/2l + \sinh^2\pi x/2l} + u_0\,(y - l/2)\,[(y - l/2)^2/3l^2 - 1]$$

The system of streamlines is shown in the diagrams, where it is clear the type of flow depends essentially on whether

$$u_0 l/K > \text{or} < 1/2$$

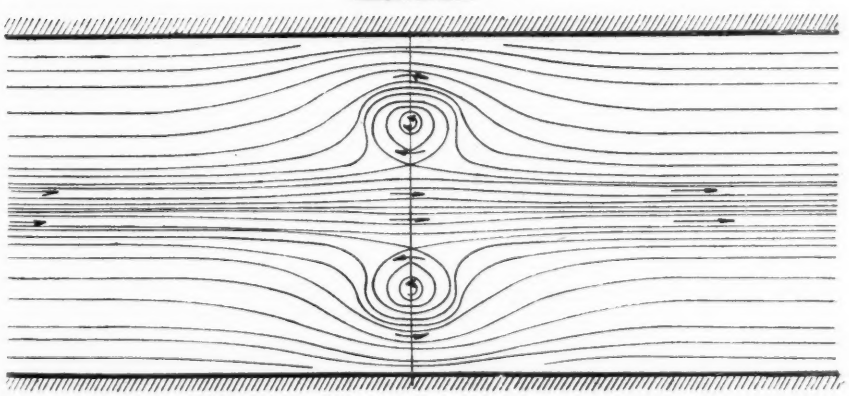


FIG. 6.

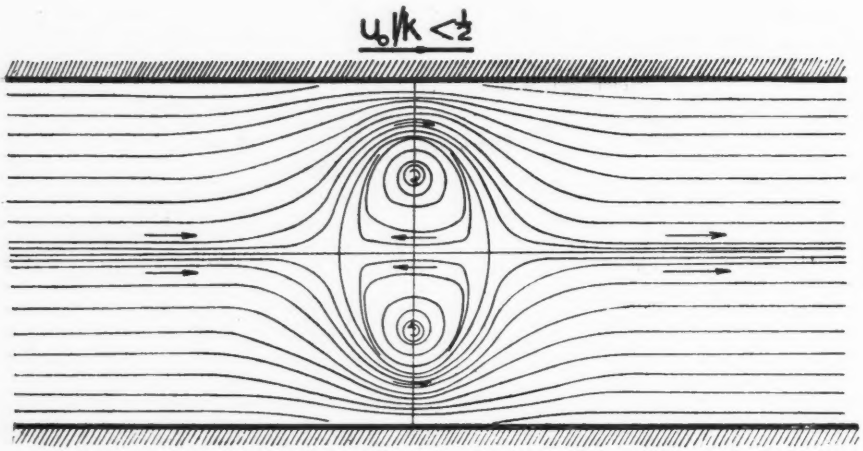


FIG. 7.

As a picture of what takes place in a real fluid it is admitted objections can be raised to the foregoing. First and foremost, although at each end of the channel the distribution in velocity is that found in a real fluid, viz., parabolic with zero velocity at the walls, in the more immediate neighbourhood of the eddies the "no slip" condition at the boundaries is certainly violated. Whether or not this is a vital objection I am unable at present to say, but a simple experiment would quickly determine this. The conditions of the problem could be constructed with sufficient accuracy by placing two thin vertical rods of circular section spinning axially in a steadily flowing channel. The angular rotation of the rods would then bear a simple relation to the strength of the eddies and by varying this angular velocity or the speed of the water, the nature of the streamlines and any critical change in flow that occurred in the region of $u_0 l/K = 1/2$ could easily be determined. If the width of the channel be 4in., the diameter of the rods $\frac{1}{4}$in., and if the speed in the channel be 1in. per sec., then the critical angular velocity from the above analysis should be approximately 6.5 revolutions per sec. A simple experiment can consequently be devised to check the foregoing analysis; but the important consideration, as far as we are at present concerned, is the fact that a critical value of vl/K is indicated even in this simple problem.

It is now no difficult matter to investigate the stability of such a system. This is important at this stage, for it indicates the method that can be adopted in all such problems and at the same time suggests an extended conception of the question of stability that is of vital consequence in all such problems.

We may, as we have seen, imagine the walls of the channel removed, provided the vortices be imaged in the sides, in this case an infinite number of times, giving an infinite trail of vortices of alternating strengths as in Fig. 8.

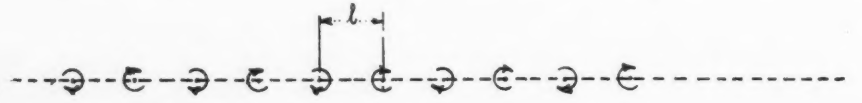


FIG. 8.

Let the displacements of the nth vortex be represented by (ξ_n, η_n), the co-ordinates of this vortex being therefore $(nl+\xi_n, \eta_n)$, then the instantaneous velocity set up at the vortex $n=0$ is

$$-u_0 = \frac{K}{2\pi} \cdot \sum_{-\infty}^{+\infty}{}' \frac{(\eta_n - \eta_0)(-1)^n}{(nl+\xi_n-\xi_0)^2+(\eta_n-\eta_0)^2}$$

$$v_0 = \frac{K}{2\pi} \cdot \sum_{-\infty}^{+\infty} \frac{(\xi_n+nl-\xi_0)(-1)^n}{(nl+\xi_n-\xi_0)^2+(\eta_n-\eta_0)^2}$$

$n=0$ being of course omitted.

Remembering that $u_0=d\xi_0/dt$, $v_0=d\eta_0/dt$, and retaining only terms of the first order of small quantities

$$-\frac{d\xi_0}{dt} \cdot \frac{2\pi}{K} = \sum_{-\infty}^{+\infty} \frac{(\eta_n-\eta_0)(-1)^n}{n^2l^2} = \eta_0 \sum_{-\infty}^{+\infty} \frac{(M-1)(-1)^n}{n^2l^2}$$

$$\frac{d\eta_0}{dt} \cdot \frac{2\pi}{K} = -\sum_{-\infty}^{+\infty} \frac{(\xi_n-\xi_0)(-1)^n}{n^2l^2} = -\xi_0 \sum_{-\infty}^{+\infty} \frac{(N-1)(-1)^n}{n^2l^2}$$

on setting

$$\xi_n = N\xi_0 \qquad \xi_1 = a\xi_0$$
$$\eta_n = M\eta_0 \qquad \eta_1 = b\eta_0$$

M and N being functions of n determined from the fact that the vortices constitute an infinite series of images in the walls of the channel.

Hence

$$\frac{d^2\xi_0}{dt^2} = \frac{K^2}{4\pi^2} \cdot \frac{\xi_0}{l^4} \left[\sum_{-\infty}^{+\infty} \frac{(M-1)}{n^2}(-1)^n\right] \cdot \left[\sum_{-\infty}^{+\infty} \frac{(N-1)}{n^2}(-1)^n\right]$$

which in this case can be shown to reduce to

$$\frac{d^2\xi_0}{dt^2} = \frac{K^2}{128l^4}(1-b)(5-3a)\,\xi_0$$

It follows at once that the condition whether or not the position of the vortices is stable to the small disturbances (ξ_0, η_0) $(a\xi_0, b\eta_0)$ is equivalent to the condition whether or not

$$(1-b)(5-3a) \lessgtr 0$$

Graphically this may be represented by the following diagram.

If the disturbance $(a\xi_0, b\eta_0)$ lies in the shaded region the motion is unstable; if in the unshaded region, stable.

The foregoing discussion indicates at once the difficulty that arises probably in every case where an infinite trail of vortices is concerned—or its equivalent due in this case to the presence of the parallel walls. It cannot be stated categorically that the system is stable to small disturbances, but the effect produced depends absolutely on the magnitude and direction of the disturbance. If this difficulty arises in the present case where the fluid is devoid of viscosity, doubtless a corresponding state of affairs exists in a real fluid and indicates immediately the difficulties that must arise in any elementary discussion of that question.

The foregoing illustration, it must be borne in mind, is not suggested because of any hope of its being immediately applicable to any aeronautical

problem, but rather because it shows that this line of attack gives some promise, if pursued, of ultimately providing such application.

In this problem the strength of the eddies has been presumed given and the conclusions that have been drawn have not been affected in any way by that assumption. In any actual case, however, the strengths would require to be determined by some experimental fact, such as the velocity of the fluid at some point other than the boundary. As an illustration of what I mean, consider the problem of the flow past a circular cylinder; aerodynamically both a circular

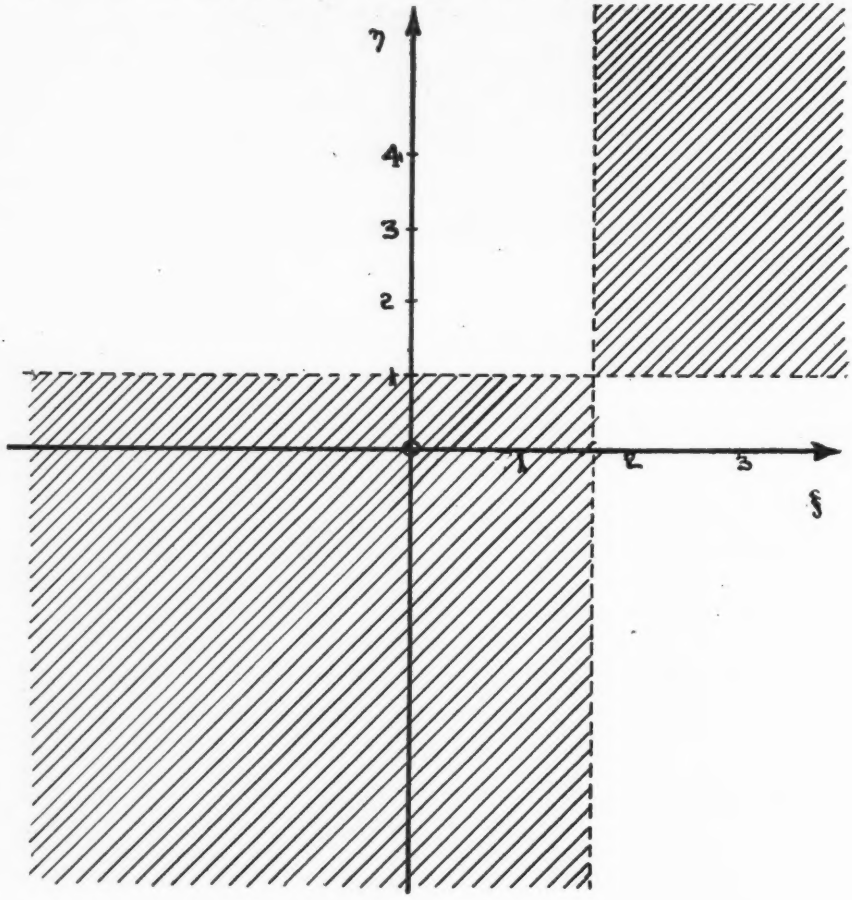


FIG. 9.

cylinder and a sphere are extremely awkward bodies in spite of their simple geometrical shape. In the former case two types of flow are known to be possible. On the one hand it is associated with a periodic formation of eddies shed off alternately from each side, and on the other shed off simultaneously. There can be no doubt that the question which of these two states will originate, will depend on their stability at the particular value of vl/ν considered.

For the purpose of the present illustration we shall restrict ourselves only to the case where the eddies are formed in symmetrical pairs, and this for a very good reason. The two eddies immediately after formation occupy a position in the rear of the cylinder and appear to remain there for some time, as it were, in equilibrium. Fig 10 is a photograph of the flow as obtained by Föppl.

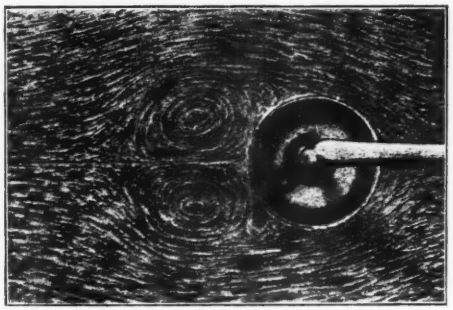


FIG. 10.

It is proposed to investigate whether a position of equilibrium exists for two eddies behind a circular cylinder, and assuming them to occupy that position, to determine how the resulting system of streamlines compares with that obtained in the actual photograph above.

Suppose a vortex pair of strengths $+K$ and $-K$ has been shed by the cylinder and that they are situated symmetrically to the line of motion in the rear of the body at the points

$$z_1 = x_1 + iy,\ \bar{z_1} = x_1 - iy$$

the circular cylinder supposed at rest in the fluid moving with general translational velocity V. As far as mutual effects of cylinder and vortices are concerned, the former may be replaced by images at the inverse points, $-K$ and $+K$ respectively, so that the stream function for steady irrotational motion past the cylinder may be added to that due to the vortices.

$$\therefore\ w = V(z + 1/z) + \frac{iK}{2\pi}\log\frac{z - z_1}{z - \bar{z}_1} \times \frac{z - 1/z_1}{z - 1/\bar{z}_1}$$

giving as the stream function

$$\psi = Vy(1 - 1/r^2) + \frac{K}{4\pi}\log\frac{[(x-x_1)^2+(y-y_1)^2]\,[(x-x_1/r_1^2)^2+(y+y_1/r_1^2)^2]}{[(x-x_1)^2+(y+y_1)^2]\,[(x-x_1/r_1^2)^2+(y-y_1/r_1^2)^2]}$$

where $r_1^2 = x_1^2 + y_1^2$.

The streamline $\psi = 0$ is clearly satisfied by $y = 0$ and by $r = 1$, which verifies the boundaries.

The velocity of the eddy at $z = z_1$ is easily found to be (dropping suffixes)

$$u = V\left(1 - \frac{x^2 - y^2}{r^4}\right) + \frac{K}{2\pi}\left[\frac{1}{2y} - \frac{y}{r^2 - 1} + \frac{y(r^2+1)}{r^4 + 1 - 2(x^2 - y^2)}\right]$$

$$v = -V\frac{2xy}{r^4} + \frac{K}{2\pi}\left[\frac{x}{r^2 - 1} - \frac{x(r^2 - 1)}{r^4 + 1 - 2(x^2 - y^2)}\right]$$

If it is in equilibrium $u=0$, $v=0$, and consequently from the above, after a slight reduction, and supposing the radius of cylinder l instead of unity

$$\pm 2y = r - l^2/r$$

$$\text{and } Vl/K = \frac{2lr^5}{2\pi (r^4 - l^4)(r^2 - l^2)}$$

This is a definite curve corresponding to the locus of the positions of equilibrium, its form being given in Fig. 11, and for each value of Vl/K there corresponds a definite pair of points in this curve which the eddies must occupy.

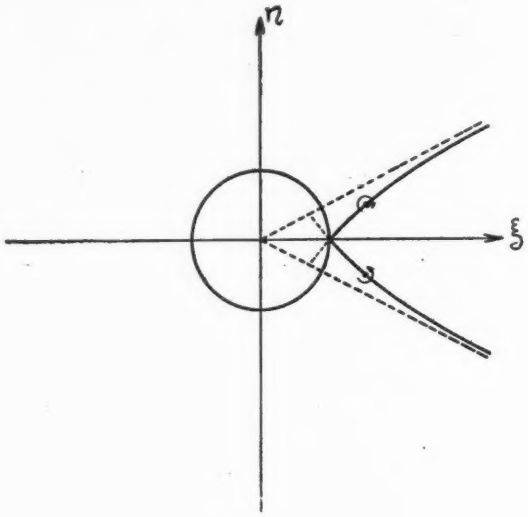


FIG. 11.

A first check on the validity of this analysis with reference to a real fluid will be furnished by determining whether the centre of the eddy in the photograph lies on the equilibrium curve. By measurement I find

$$y = .67\, l$$

$$r = 1.89\, l$$

while for the same value of r the curve gives

$$y = .68\, l$$

This in itself is sufficiently encouraging to justify further comparison. For this point on the equilibrium curve

$$Vl/K = \frac{1}{2\pi \times .63}$$

$$\text{or } K/2\pi = .63\, Vl = .63$$

taking l and V as unity.

Inserting these values in the expression for ψ obtained above, the form of the streamlines is easily found and plotted in the annexed diagram, either directly from the equation, or by superposing on the flow due to each of the vortices separately, the steady streaming past the cylinder.

The remarkable similarity between the final streamlines and those of the photograph is extremely encouraging.

If in the real fluid the equilibrium position of the eddies was in addition one of stability, each pair on production would tend to move into this position and reinforce the pair already there. But actually it is found that this pair gradually leaves its position, making room for the next pair, and, moving down the fluid, dissipates ultimately under the action of viscosity. Actually, therefore, the position is one of unstable equilibrium. It would be interesting to consider whether this is also the case with the problem we have considered. Mathematically this is not difficult, although the algebra is rather long, so that only the principal results will be given. Let the four vortices be situated at the points

$$x_1+iy_1,\quad (x_1+iy_1)/r_1^2,\quad x_1-iy_1,\quad (x-iy_1)/r_1^2$$

and suppose the first receives a slight displacement so that it instantaneously takes up the position

$$(x_1+\xi)+i\,(y_1+\eta)$$

then its image will occupy the position

$$[(x_1+\xi)+i\,(y_1+\eta)]\ /\ [(x_1+\xi)^2+(y_1+\eta)^2]$$

and the horizontal axis will no longer be a streamline.

As before, the velocity components of the first vortex are then easily deduced for this arrangement. These two components are of course $d\xi/dt$ and $d\eta/dt$.

Retaining only terms of the first order in ξ and η, assumed small, this will be found to give

$$\frac{d\xi}{dt} = A\xi+B\eta$$

$$\frac{d\eta}{dt} = B\xi+A\eta$$

where

$$A = \frac{2V}{r^6}(r^2-4y^2)\,x - \frac{Ky}{\pi}\left[\frac{1-1/r^4}{r^2+1/r^2-(2/r^2)\,(x^2-y^2)} - \frac{1}{(r^2-1^2)^2}\right]$$

$$B = \frac{2V}{r^6}(3r^2-4y^2)\,y + \frac{K}{2\pi}\left[\frac{1}{4y^2} + \frac{y^2-x^2-1}{(r^2-1)^2} + \frac{(x^2-y^2)\,(1-1/r^4)-2}{r^2+1/r^2-(2/r^2)\,(x^2-3)}\right]$$

giving

$$\frac{d^2\xi}{dt^2} = (A^2+B^2)\,\xi$$

$$\frac{d^2\eta}{dt^2} = (A^2+B^2)\,\eta$$

indicating that ξ and η increase indefinitely with time and the position in this case also is one of instability, and the eddies will move off along a path determined, initially at least, by the nature of the disturbance.

Summing up then, it may be said that in addition to the close correspondence between the system of streamlines in the real and in the assumed case, the posi-

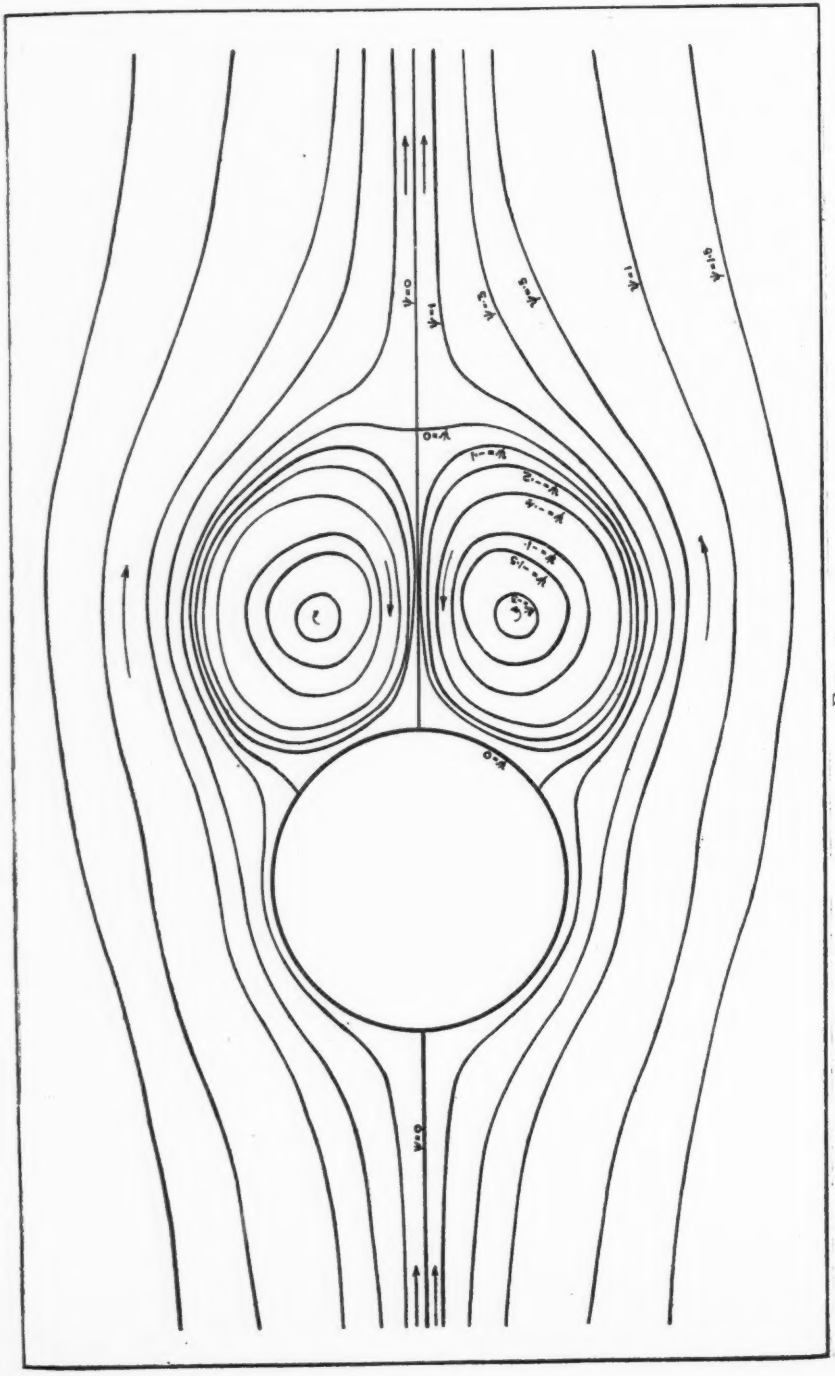


FIG. 12.

tions of equilibrium coincide, and these are also positions of instability. But one must not be over optimistic about the similarity. It has been supposed that the distribution in vorticity would be adequately represented by supposing it concentrated at the two distinct points of equilibrium. In the actual case this is probably considerably from the truth, for the vorticity will spread continuously throughout the whole of the fluid, falling off rapidly, however, from the points of concentration. To the extent to which this has been ignored we must expect discrepancies in the comparison. The principal point where the correspondence undoubtedly fails is with regard to the fluid velocity immediately over the surface of the body, where in the problem solved above, there is distinct slip, but this discrepancy is a measure, not of the failure of the method, but of our lack of experimental knowledge of the actual distribution in vorticity. It is a point on which direct experiment will provide the requisite information.

The foregoing illustrations appear to me sufficiently encouraging to warrant further investigation along the lines indicated. The method is essentially a combination of experiment and theory; by means of the former the general distribution of vorticity and points of concentrated eddying are determined. With this distribution in vorticity in a fluid now devoid of viscosity the type of flow can be determined and the properties that require investigation are now amenable to mathematical treatment.

The expression for the resistance of the body—if this is desired—although from the present point of view I consider this of minor consequence compared with an analysis of the circumstances of the motion—is

$$R = \rho V^2 l^2 f\,(Vl/K)$$

and this may be calculated in any given case from a consideration of the energy required to establish the motion.

I must not dwell too largely on this aspect of the question, but the point I wish to emphasise is that by the method outlined above, based on certain easily derived experimental facts, a field is opened up which will enable us to lay bare and explain many aspects of the aerodynamical meaning of the transition from model to full scale, hitherto not understood or at best obscure. Although a vast amount of experimental data has been accumulated both for models and for full scale, it is clear that the theoretical explanation of these facts is still in its infancy.

Applied mathematicians will find in this, as in other branches of aeronautics, a splendid field for fruitful research. For each experimental fact there exists some theoretical interpretation which, if viewed from the correct angle, will throw a sharp light not merely on the problem of the passage from model to full scale, but on the whole question of efficient design.

PROCEEDINGS.

TENTH MEETING, 54th SESSION.

The Tenth Meeting of the Session was held in the Theatre of the Royal Society of Arts, London, on Wednesday, February 26th, 1919, Lieutenant-Colonel A. Ogilvie, C.B.E., R.A.F., presiding.

The CHAIRMAN said he had the pleasure of introducing Captain Barnwell, if an introduction was necessary. As most of the audience knew, he had been designing for the Bristol Company for some years, although he (the Chairman) believed he would much rather have taken a more active part. When he tried to escape from the net, it was very strongly opposed from the Technical Department. To give an idea of his work one or two of his most successful machines might be mentioned. He should, perhaps, first refer to his Bristol Fighter, as probably the most successful machine there had ever been for two-seated fighting and the machine which, so far as two-seated fighting went, had done more than any other machine to put us in the position of superiority on the front. He remembered when the machine was first flying at the Central Flying School. He did not know Captain Barnwell then, but a fellow he knew, who was there, wrote to him about an extraordinary machine which was being turned out by the Bristol Company, in which the pilot and observer were sitting in one another's laps. That showed the clear way in which Captain Barnwell saw what was required for two-seated fighting. Since then there had been thousands made, and the machine had steadily increased its reputation. Another notable machine was Captain Barnwell's monoplane—an extraordinary fine machine of its time. He would now call upon Captain Barnwell to read his lecture.

Captain F. S. BARNWELL, R.A.F., then delivered his lecture.

DISCUSSION.

The CHAIRMAN said he thought the best recommendation he could make with regard to the Lecture was that they should read, mark, learn, and inwardly digest it. It was not a thing that it was possible to criticise off-hand, although he saw some people there who might like to make some remarks upon it. Designers would, he was sure, feel a big debt of gratitude to Captain Barnwell for his clear exposition of his methods of calculation and design. At first he (the Chairman) did not realise exactly what this work was that he was putting before them, but towards the finish, when he got to the front views of the three machines, he saw where it was tending, and it was very interesting to see the calculation and investigations which he had made in order to arrive at the result which he (the Chairman) expected they would see later on in the form of an actual machine. The Lecture showed how necessary it was to make careful and laborious investigations into the points dealt with by Captain Barnwell, and he was certain that such methods were really the basis of the methods on which our design could be called successful against that of other countries. Many people thought all that was necessary was to guess, but real basis of guess work was the sort of stuff Captain Barnwell had put before them. He would like to remind Captain Barnwell of the Caudron training machine, in which the trailing edge was flexible and the two spars were very close together. The front spar was not very near the leading edge, and there was a very wide trailing edge which was very flexible.

Mr. R. A. BRUCE said, speaking generally, he thought the method Captain

Barnwell had adopted and described was one which others might repeat with great advantage. He understood that the method was to proceed from known data rather than by employing purely mathematical analysis, and trace the consequence of varying each factor by small steps or gradations, and then deliberately following up the results of so doing, and so obtaining, or endeavouring to obtain, the optimum conditions attached to each case. They had seen the method successfully applied to very elaborate problems. Those who had attempted to make similar comparisons between the various wing structures would have encountered the same difficulties. The lecture was of great educational value, because it showed how, in dealing with problems of this sort, it was necessary to preserve consistency throughout, and Captain Barnwell had started at the very foundation and proceeded by a logical method, step by step, till he was able to apply each succeeding investigation to that which followed and thus arrive at a final result which could hardly be more sound and logical. The photographer had not been kind to Captain Barnwell as regards the legibility of the slides shown on the screen, but even had every one of the curves and figures been legible it would have been impossible, as far as the speaker was concerned, to have thought swiftly enough to have obtained a full grasp of the subject. They could only do as the Chairman had said—read, mark, learn, and inwardly digest the Paper when it came before them—and he thought it would be an admirable thing if others would follow in the wake of Captain Barnwell, and give results on very much the same method. He felt that this method was more valuable to designers than any mere process of mathematical analysis values, because except to certain very limited numbers the equations obtained concealed rather than revealed the results.

Mr. F. H. Bramwell said Captain Barnwell was, obviously, in many places up against the dearth of information. In his aileron analysis he had merely two sets of aerofoil tests, with flaps alike as to length but of different widths, and from those two sets he had to plot out that elaborate system of curves showing the best type of aileron to use; other people who had tried somewhat similar investigations always came up against the same fact, that the amount of information available was extremely limited, and the results, which depended upon the training and the amount of judgment brought to bear on the problem by the investigation, would differ very widely. Captain Barnwell had given a great deal of credit to experimental model work, in other words, had shown the advantage that would accrue from further model work of that type. He felt that he must back him up to the best of his ability in pointing out how much they depended on those investigations. Full-scale work was also needed, but investigations involving many small changes could only be done cheaply and quickly on models. It was comforting to find that in Captain Barnwell's curves the maximum or minimum always occurred at the flat part of the curve. In the curves for spar weight against position in the wing, and also the curves for tail plane resistance against position of centre of gravity, and so on, they were all very flat. One could change the position of the spars in the wing with a very small percentage change in the spars. That was very comforting when one realised the meagreness of the information on which the investigation was based. Captain Barnwell had assumed a uniform section spar throughout, and mentioned that it would not necessarily be of the lightest weight. They were coming along to built-up metal spars in which, possibly, uniform section would not be so necessary. He thought, however, Captain Barnwell would agree that a big advantage of a uniform section spar was ease of manufacture. With regard to Captain Barnwell's equation of head resistance and weights of struts, wires, and so on, he was sure Captain Barnwell had realised that the relation between the head resistances and the weight varied with the height of the machine. He took it the figures referred to ground-level conditions. In the curves for machine moment and tail plane moment the machine was assumed to trim with main planes at 2°, and with many of the positions of centre of gravity there was a big moment which had to be balanced by the

tail. That meant that the curves for tail plane moment, if they were taken with the elevator in line with the tail plane, would probably necessitate quite a big pull on the pilot's hand to hold the machine in that position. Would Captain Barnwell go into that a little further, and amplify the curve to provide for trimming the machine, with possibly an elevator angle, but no load on the pilot's hand.

Mr. A. J. SUTTON PIPPARD said he believed the hard work method of plugging through the actual calculations, as Captain Barnwell had done, was going to give a better result than a mathematical way. He had just been doing work on the problem Captain Barnwell mentioned of the placing of the struts in the wing structure. In the scout machine it was simple, but with two or three bays it became difficult, except by actually taking examples. In the scout machine he found the strut should be placed about one-third of the length from the wing tip. He imagined that would agree with Captain Barnwell's figure. Captain A. H. Stuart, of the Air Ministry, in an early R. and M. Report, gave particulars of experiments on the vibration of a spar. He found that if the inter-plane strut was at a greater distance in from the wing tip than one-third of the half-span of the spar he had considerable vibration, so the economical spacing for the strut and the conditions for a small amount of vibration were pretty consistent. The question of that factor came into the decision strongly. He did not know whether Captain Barnwell had taken it into account. If one took a machine flying steadily horizontally and got a position for the strut, then with three or four times the load, it would be slightly different. In the scout machine it only varied slightly round about .33. He thought Captain Barnwell's method in making the stability curves, though accurate, might be shortened somewhat if, instead of plotting the actual curves of the moments, he plotted the slope of the curves, which showed the results straight away. It would save all that work with the tracing and sliding along. He thought Mr. Bolas originated the method he suggested. There was no need to plot the two sets of curves against each other. Perhaps Captain Barnwell would like to develop that. He believed it was somewhat similar to Captain Barnwell's method.

Captain MORRIS said the work done by Captain Barnwell was extraordinarily good, but as Captain Barnwell himself had informed them, a good deal of the paper could not be trusted without further work. It struck him that the performances of the three machines which were compared were rather similar, and that statements made on the basis of slight differences might not be correct. He did not think it quite correct to lay down a general law from what had been found in a particular case, which, they were told, might be somewhat out. Mr. Bruce rather threw cold water on analytical methods, and insisted that methods similar to those employed by Captain Barnwell were absolutely the thing. He could not agree with that. So far as he had grasped Captain Barnwell's methods and conclusions, he did not think that they were justified in deducing general laws from them without more evidence. Also it was not fair to science to say that you could not attain particular results by analytical processes. Very frequently some peculiar relations were discovered and solutions obtained from which laws could be obtained more accurately and with greater facility than from laborious experimental work based on arbitrary assumptions.

Mr. W. H. BARLING said, with regard to the spar depths of large machines, they did not really need, as the machines got larger and larger, the spar depth which would be given by Captain Barnwell's standard aerofoil. If one made the spar depth as large as the section would allow, one did not always get in a large machine the most economical weight of spar. If it had to be packed or any jobbing had to be done to get the original aerofoil shaped, weight was lost again. It depended also on the type of spar, but there was a point at which, if the machine were made larger and larger, the aerofoil shape could, if desirable, be changed to make it more hollow on the under surface. He thought it better to dodge the

point by pushing the spar very far forward, getting it of less depth, and dodging any packing out. He quite agreed with Captain Barnwell in regard to strut weights. Strut weights acted in a very curious way. With a span of very great length one should have very short struts, and with a large machine one should have very short struts, and with a large machine, if the job were done completely, a hangar would have to be designed to take this big span. With a 150ft. span one would require a roof something like the span of the old Charing Cross roof. One got rather worried with the machines getting bigger and bigger. Designing the hangar for them was almost as big a problem as the machine itself. He would have liked to have heard Captain Barnwell say something about metal construction in aeroplanes.

Mr. H. BOLAS said Captain Barnwell had forgotten his ribs until the end. Extremely flexible ribs were not very good. He thought Colonel Ogilvie mentioned the Caudron, and another flexible rib was the Breguet. Captain Barnwell said the centre of pressure for full-sized machines was probably the same as in the model. The R.A.F. did a test with a full-sized machine of which the tail was hinged. To measure the pressure accurately, what they measured was the moment about the hinge and the fuselage, and from that could be measured the position of the centre of pressure on the main spans. In the case of the R.A.F. 14 that varied extremely from the model tests, and generally the C.G. was much further forward. This influenced the tail calculations to a considerable extent. With regard to the investigation of sizes of tails, raised by Mr. Pippard, he would like to talk to Captain Barnwell about that matter, which was extremely simple. It boiled down to the rate of change of moment, rather than the actual moments themselves. Captain Barnwell took rather a rough method in calculating tail area, as the down-wash co-efficient varied considerably. It was different from different angles. If one obtained the area necessary at any particular angle, and multiplied by the downward co-efficient, one got the angle required. If the area were taken for some other angle the down-wash co-efficient was different. Certain figures were quoted for the best position of the centre of gravity as affecting the climb at top speed. That depended upon the accuracy of the centre of pressure figures very greatly. He had made trials of the different gaps and the different positions of centre of gravity, and his results generally had agreed fairly well with Captain Barnwell's figures. The actual curves were fearfully flat, but the difference had not been great in different types. By having a bigger gap, the weight of the main plane structure was increased, which made it better from the lift point of view, but the actual result on climb was not very big really. He could not understand Captain Barnwell's remark that the weight of the tail had to be paid for in wing drag. Mr. Bramwell had raised the point that Captain Barnwell had only two positions for the wing flaps. It would be interesting to get a further number of experiments made by the N.P.L. shifting the position of the wings further than .22. Instead of plotting against the angle, the better way was to plot the moment about the hinge against increase of K_y, or lift. One was not interested in the angle itself, but in the moment about the hinge as compared with the lift.

Captain BARNWELL, replying to the discussion, said that he considered that the strength of the Caudron machine (mentioned by Colonel Ogilvie) in flight was due largely to the wide flexible trailing edges of its wings; he believed that it showed up poorly under sand loading when this flexibility would not relieve the wing structure.

In reply to Mr. Bramwell, he hoped that they would soon obtain the results of many more experiments on model wings with flaps of varying breadth and length. He considered that the value of wind tunnel work on models could not be rated too highly, as not only could results be obtained quickly and cheaply, but also with a high degree of "definiteness" by this method. In work with full size machines out of doors it was extremely hard to obtain the requisite

constancy of all conditions other than that one whose variation was to be investigated.

As regards form of spar section, he had considered only the uniform section because it was the simplest to estimate about. The equations for head resistance of struts and wires were for resistance in air of "standard" ground level density, .00237lbs. mass per cubic foot.

As regards figures given for tail size, he agreed that the hinging of the elevators would entail a certain load on the pilot's hand. It would be a rather complicated problem, however, to investigate the effect of "free" elevator flaps, the tendency would be, of course, to decrease the stabilising power of the whole tail and therefore to call for a larger tail area. Probably the use of a tail plane of high aspect ratio, with very narrow elevator flaps, would minimise the load on the pilot's hand whilst still affording sufficient control power.

In reply to Mr. Pippard, he found that the correct position for the strut along the spar of a single bay job with pin joint at inner end, was:—

$$\text{Length of overhang} = l + .2 \text{ (wing chord).}$$
$$\text{,, bay} = (1 + \sqrt{2})\, l.$$

He had not considered the question of spar vibration, and on the figures quoted by Mr. Pippard it would appear that for a wing of low aspect ratio the overhang length (as just quoted) would be too great from this point of view. If, however, the vibration experiments were made on a bare spar, then most probably the liability to vibration in a complete wing would be much less, and the overhang might safely be made longer.

As regards investigating longitudinal stability, he was very interested to hear of the method of plotting the slope of the pitching moment curves, and hoped that Mr. Pippard or Mr. Bolas would find time to publish an account of this method.

In reply to Mr. Barling, he had never been concerned in the design of an aeroplane so large that it was not profitable to make the wing spars occupy the full depth of a wing of normal section. As a matter of fact he was rather puzzled as to why this should be so, for presumably the spar section could not become smaller, proportionately, due to increase in scale size. Presumably it occurs because the points of support are spaced closer together relatively, and the "factor of safety" lower, in a large than in a small machine? He agreed that the soundest way to reduce the spar depth, if necessary, would be to move the front spar forward and the rear spar aft. He agreed that the question of sheds for very large machines became a very serious one. In view of the fact that height was cheaper than roof span, the claims of the multiplane (three or more) should be considered for large machines.

In reply to Mr. Bolas, he agreed that flexible ribs were not very satisfactory, mainly for structural reasons and because the flexibility introduced many more difficulties in calculations for strength and performance; but flexibility, in the right place, might be a very valuable method of reducing the flight stresses, without increase of weight, and this should not be overlooked.

He had heard of the full size experiments on centre of pressure position done at Farnborough, but had been under the impression that they had agreed fairly closely with the results of model tests.

He hoped to have an early opportunity of seeing Mr. Bolas' method of investigation for tail plane size. As regards the question of down-wash, he agreed that for accuracy this effect should be included from the start in calculations for tail size; but the results of a series of down-wash experiments had been issued as a confidential report only quite recently, so he had hesitated about using them for publication and had, as a matter of fact, only used what had been done some years ago on a BE2C model. But he did not consider that the rough

approximation method of allowing for down-wash (as in the paper) would make for serious inaccuracy in the finding of optimum fore and aft C.G. position, and of course it considerably simplified the work.

As regards the question of weight of tail, his point was that any machine might be considered as of constant weight *without* its tail; so if the weights were disposed so as to give a far forward position of C.G. (relative to wings) then would only have to be added a small and therefore light tail, whereas if the weights were disposed so as to give a farther back position of C.G. then would have to be added a larger and therefore heavier tail.

As regards the question of the advisability of plotting curves for flap values on a base of angular setting of flap, this was necessary in the method adopted (in the paper) as the amount of angular setting of flap determined the leverage of the load applied by the pilot.

A vote of thanks to Captain Barnwell (moved by the Chairman) concluded the meeting.

PROCEEDINGS.

ELEVENTH MEETING, 54th SESSION.

The Eleventh Meeting of the Session was held in the Theatre of the Royal Society of Arts, London, on Wednesday, March 12th, 1919, Dr. T. E. Stanton presiding.

The CHAIRMAN said the object of the meeting was to listen to a discourse by Mr. Levy on the subject of "From Model to Full Scale in Aeronautics." It was fitting that a discourse on that subject should be given in that hall, because it was from that platform almost exactly 42 years ago that Froude first enunciated his law of the comparison for the wave-making resistance of ships, which was now used for all ship design. It was hardly necessary for him to introduce the lecturer. Mr. Levy was joint author of an able text-book in aeronautics and a member of the staff of the National Physical Laboratory in which was initiated the science of the application of model results to full scale aeroplane work. The subject was still in its infancy, and there was a vast tract of undiscovered country yet to be surveyed. From his (the Chairman's) experience, he thought that in the opening up of that region Mr. Levy would be one of our foremost pioneers. It was on one method of research in connection with that subject that Mr. Levy wished to address them.

Mr. H. Levy, M.A., B.Sc., F.R.S.E., then delivered his lecture.

DISCUSSION.

Mr. L. BAIRSTOW congratulated the author on his interesting exposition, and said he had spared them a good deal of mathematics, though it was necessary to work up to the final solutions he gave in his last illustration. The fact that so near an approximation of an actual eddying flow could be got should tempt other people to follow on the same lines. Much of the work the author had mentioned on dynamical similarity had been worked up in the last few years, and it had a great fillip due to the introduction of aeronautics. There was one point on which he rather differed from the author, and that was in regard to his statement that the motion of a viscous fluid necessarily involved eddying. Perhaps he did not go quite so far as that, but he showed one illustration in which water flowing past a thin flat plate did not show a trace of eddying, nor did he (Mr. Bairstow) believe there was any mathematical necessity for the assumption that eddying was always associated with the motion of an actual viscous fluid. He congratulated the author and the Society on the opportunity which the lecture gave of drawing attention to the theoretical aspects of aviation. He thought the illustration the author had given was the nearest approximation that had been obtained to any actual flow round the parts of a structure entering into aircraft. They had circular wires, and the eddies were reproduced to some extent there. No such near approximation had ever been made before. During the war they had made rapid strides, but the method had been very direct attack. They could not wait until things were worked out, and the force of circumstances had necessarily driven them to trial and error methods. Those who had been intimately connected with the work realised how poor a substitute that was for theoretical and scientific research. It had been costly in money and in loss of life, and he hoped that Society would take further opportunities of bringing papers before them to show how the development of aeronautics—particularly in the years to come—

would depend on their not confining their attention to the immediate practical needs of the moment, but on using their theories, in order to get somewhat further ahead.

Mr. F. H. BRAMWELL said the lecturer made what he thought a rather bold statement in regard to executing the *Vl* correction from model to full scale. He thought perhaps he rather exaggerated there. The evidence for the full scale was not very complete, but there was a fair amount of evidence on full scale work on certain parts of aeroplanes—the main planes for instance—which helped to fix the top points and did not entail absolute guessing from the model value right up to the full scale.

Lieutenant-Colonel R. DE VILLAMIL: I should like to ask the lecturer how he reconciles the so-called "dimensional effect" with dynamical similarity. He certainly makes no mention of it in his book, but it is, apparently, an article of faith at the National Physical Laboratory, and I know that the Chairman is a great supporter of this idea.

I am aware that the two assumptions are self-contradictory; but such a trifle does not disturb the equanimity of a mathematician.

Mr. Levy says that the effect of the compressibility of the air on resistance is quite negligible at ordinary speeds. Some months ago Professor Bryan wrote a short article on this subject, which was published in the JOURNAL; and in this article he had a quiet dig at me. This was, of course, quite fair; but as I do not take these things lying down, I very promptly sent in a reply. It was never published, as I was informed that the subject was "not of sufficient importance for the JOURNAL."

The question is now brought up again and Mr. Levy bases his opinion on "Bernoulli's" work. He does not say *which* Bernoulli, nor where the information is to be found. Presuming, however, that it was Daniel, I might point out that, though he was very clever, he was not infallible. He it was who showed that the pressure in a liquid in motion might be *greater* than that of the same liquid at rest. This is referred to approvingly by Mach in his "Mechanics," who also gives Daniel's proof. The mathematics are all right, but the fundamental assumption is wrong, and the result violates the principle of the conservation of energy.

Mr. Levy gives that part of the formula which causes the increase in the resistance due to the compressibility of the air as $[1 + v^2/4V^2 \ldots]$, with other terms which are negligible, and when V is the speed of sound waves.

This formula will give results which do not agree with experiment. The correct one is, as I have shown in "Resistance of Air," $[1 + v/V]$, where V has nothing to do with the velocity of sound, but is the speed of the *flow into a vacuum*.

Mr. Levy says that the error, at 150 m.p.h. caused by assuming the air to be incompressible, is of the order of *one per cent.* I, on the contrary, maintain that it is of the order of *sixteen per cent.*—not, by any means, a negligible amount. It is not extraordinary, therefore, that a lecturer lately told us that full-scale experiments do not give results which agree very closely with those prophesied from the results obtained from models.

The question can easily be put to the test. I therefore challenge Mr. Levy to calculate and make a table of the resistances experienced by a four inch spherical shot at speeds of 100, 200, 300, up to 2,000 feet per second.

If he is unable to do this I will promise to supply the solution of the problem, which is not a very difficult one.

Mr. VAN BAUMHAUER (Member of the Dutch Aëronautical Society) said he thought Mr. Levy had shown for the first time, from a mathematical standpoint, observations of what occurred in the air fluid round a real body which agreed in a high degree with the flow of viscous and continuous fluids round a body. Mr. Levy said that taking the place of the two vortices he found a certain field of streaming round, and said there was some leakage. Perhaps he could find the form of the body which would be equal to the vortices. It would not be a circular cylindrical body. Perhaps the author could go on and place the other points differing from the original vortices used and find another body, and adding the stream lines above each other, find the places of the other vortices in quantity and quality to give the real solution. The stream round the body was not cylindrical, and he supposed the author would find the places where to put the vortices, which must be added to the streaming he had shown to get a real circular cylinder. If the places for those vortices could be found the pressures could be calculated from the lines along the surface of the cylinder in the illustrations and compared with the pressures on the real cylinder measured in the laboratory.

Lieutenant WILLIAMS asked whether Mr. Levy had analysed some of the photographs to get the distribution of the velocity in the vortices. He presumed that in the calculation Mr. Levy took the distribution of velocity to be that given by the usual vortex theory. When he (Lieutenant Williams) was doing work on that subject before the war, Karman's results came out, and, comparing them with his photographs, he found that at low resistances, at all events, the centre part of the eddy seemed to rotate like a solid body. That might help to make the approximation more exact. He wondered whether that point was confirmed by photographs taken at the N.P.L.

The CHAIRMAN said he was afraid there might be an impression that this paper was an extremely theoretical one. He thought there was a very practical bearing in connection with Mr. Levy's suggestions. He understood Mr. Levy was out for the total abolition of wind channels, *i.e.*, if any wing section were being investigated its aerodynamical properties should be calculated from the shape of the wing section, and not by being put in a wind channel to determine the lift and drag. It was a very practical thing, though very ambitious at the present time. A good analogy might be seen in the case of the theory of structures. If it were imagined that the theory of elasticity had never been developed, they might now be making models of their bridges and testing them to destruction by loading, and designing their bridges from the results of the tests on those models. But their knowledge of the molecular movement, commonly known as stress, was now so good that there was no necessity for that. It was that model testing that he understood Mr. Levy wished to do away with. As far as his experience went, he thought the actual conditions in fluid motion might be more favourable to the method Mr. Levy advocated than he had assumed. He had proceeded, it appeared, on the usually received opinion that there was no possible slip at the boundary of a viscous fluid in motion. He (the Chairman) was not quite sure that that was fully understood. He saw a statement the other day that if in Poiseville's experiments the shear stress at the boundary of a viscous fluid in motion was $\frac{3}{4}$lb. per sq. in. one could not expect to get any slip for shear stresses below this value. He thought that was based on a misconception. The particular experiment referred to was for a fluid flowing through small tubes, and that particular state of flow was below the critical velocity. All those demonstrations indicating no slip at the boundary of a viscous fluid were for fluid flowing below the critical velocity. He had hoped Miss Marshall would have spoken, as she was making experiments which seemed to show there was a certain amount of slip in the case of turbulent motions. It was, however, not perfectly definite.

If V were the speed at the centre of a pipe through which a fluid was in

motion and v the speed of the fluid at the walls of the pipe, then for motion below the critical value $v/V=0$. It appeared from Miss Marshall's experiments that, when the critical velocity was exceeded, v/V had a definite value, *i.e.*, there was slipping at the walls, and further, that as the mean speed of flow was increased v/V also increased and finally attained a limiting value. It was possible, however, that this conclusion might not be confirmed.

He considered the paper to be a valuable contribution to aeronautical science and he was sure the Society was very much indebted to the author. He proposed a hearty vote of thanks to Mr. Levy.

Mr. LEVY, replying to the discussion, said in regard to slip at the boundary, referred to by Dr. Stanton, there was always a difficulty in any experimental work that sought to determine the speed of the air close to a body, which threw doubt on the conclusion. The measurement could only be done by means of a very small Pitot tube, but unfortunately in the neighbourhood of the boundary the velocity decreases so rapidly that even over such a small distance as the diameter of the Pitot the total drop is comparatively large and an approximate estimate of the velocity at the centre of the Pitot mouth would require to be made. In the second place there is the disturbance set up by the Pitot itself, which can never be excluded. If one regarded the question from the molecular standpoint, however, it was clear that the molecules towards the surface of the body would be attached rather loosely and would tend to become entangled with those of the passing air, so that near the boundary there would be a gradual mixture of body and air, and a gradual transmission of momentum from one to the other. What then should be taken as the line of division—the outline of the body? A surface could be drawn in this region, which moved with the body, from which surface outwards to the fluid the gradient in velocity would be continuous even though rapid. These general grounds indicated that probably there would be no slip—no relative velocity of fluid over body, but ultimately it was a question for experiment to decide. The theoretical consequences could be considered once the experimental results could be guaranteed. Mr. Bairstow said that he (Mr. Levy) had given the impression that eddying was necessarily involved in a viscous fluid. He did not mean to give that impression. Eddying was a very loose term that was usually taken to mean that the vorticity had become visible as definite centres of rotation and was usually associated with unsteadiness in the motion. He knew that the photograph showing the slow motion past the body giving the velocity in terms of dashes did not show any eddying. They took about 14 photographs at different times of the fluid passing that flat plate, and in every case the stream lines fell exactly on top of each other. If there had been even a variation of the velocity it would have been noticed. There was not merely no eddying, but it was absolutely steady. He was not sure whether it was possible theoretically to get steady flow of that type past a cylinder, but they got it in a water channel. He was making an attack on the heavy mathematics by assuming an eddy instead of a viscosity and then making it amenable to mathematics. He did not want to give the impression that guessing was done when passing from the model to full scale. There had been a tremendous lot of work done on the full scale to check the work done on the models. He did not quite get Colonel de Villamil's point.

Lieutenant-Colonel DE VILLAMIL said he referred to what was called the dimensional effect. It was talked of in papers of the civil engineers and it was considered an article of faith, but it contradicted dynamical similarity, and he believed it was all moonshine.

Mr. LEVY said he was afraid he was one of the people who believed in it. The dimensional theory at bottom meant nothing but the application of the simple laws of Newton. If one said the expression for a force were not to have the dimensions of a force it would be flying in the face of Newton's laws. They

were founded on a large number of experimental facts and one had a large mass of evidence that enabled one to judge when Newton's laws could be applied.

Lieutenant-Colonel DE VILLAMIL said in regard to the facts about the compressibility of air it was only a matter of calculation. He had calculated a large number of cases, and in every case he found his formula gave the correct results. In calculating the resistance of a 4in. shot at 2,000ft. per second the coefficient he started with was multiplied by 1,000 millions. If one could do that and produce a correct result the formula could not be very bad.

Mr. LEVY said the formula he gave as the pressure on the nose of a body was one obtained by Lord Rayleigh and other mathematicians, and should therefore be accurate, but he would be pleased to go through Colonel de Villamil's book and try to find out whether he had made a mistake in his calculations. (Laughter.) He took it that what Mr. Van Baumhauer suggested was that an attempt should be made to find out what the distribution of the velocity was in the neighbourhood of the body, and get that distribution, as distinct from the type he had shown. That, and also the velocity inside the eddy, about which another speaker asked, would require further investigation. Those questions had been left over during the war, but now the pressure was over it was their duty to turn to those questions and see what could be made of them from a theoretical point of view.

Major-General R. M. Ruck (President of the Society) proposed a vote of thanks to the Chairman, and congratulated him on the fact that the remarkable and beautiful piece of work described by Mr. Levy had been carried out by one of the staff of the National Physical Laboratory. He was sure everyone present was interested in the Chairman's remarks, and that they would pass a hearty vote of thanks to him.

The vote of thanks was carried.

ABSTRACTS.

Naval Aircraft Factory (U.S.A.).

The article deals in the first place with the erection and development of the U.S.A. Naval Aircraft Factory at the League Island Navy Yard, Philadelphia.

The original manufacturing unit has a ground area of 160,000 sq. ft., and was built and equipped in three months at a cost of a million dollars. A large assembly plant was added subsequently, and the factory now extends over 40 acres of ground with nearly 10,000 workers employed by the factory and private firms.

Regarding internal organisation there is an Employment Division which organises an apprentice school as well as providing for the supply of man-power. The Engineering Department covers the designing of experimental and production machines and the inspection and testing of material; it also includes a Trials Section for the testing of finished seaplanes under the direction of skilled pilots. The Manufacturing Office receives the requirements of the Navy Department, and accumulates all necessary data for requisition purposes. The Supply Department ensures the rapid transportation of the finished aircraft to their destination. Also, the Contract Manufacturing Department is responsible for maintaining the output of the assembly plant at its highest capacity by supplying the component parts of the finished product for final assembly. ("Aviation," February 1, 1919.)

Aeromarine Type L 6-Cylinder Aero Motor.

A short description of this motor manufactured by the Aeromarine Plant and Motor Co., of Keyport, N.J., is given and illustrated by photographs. The motor is a six-cylinder, four-cycle engine with water-cooled valves in the head. The main portion of the crankcase and cylinder jackets are integrally cast of aluminium alloy; the cylinder head and valve gear form a complete self-contained unit removable from the motor in a few minutes, the head being of aluminium alloy with grey iron valve seats cast in position; also the pistons are of aluminium alloy ribbed under the head. The crankshaft and connecting rods are of alloy steel drop forgings.

The motor has been designed for training and sporting aeroplanes and its chief characteristics are:—

Cylinder bore 4.25 in., stroke 6.5 in.

Weight 375 lbs., with electric starter and generator 405 lbs.

Rated horse-power 130 at 1,625 r.p.m.

The motor has run up to speeds in excess of 2,500 r.p.m. and a chart giving h.p. plotted against r.p.m. gives a curve up to 2,100 r.p.m. (169 h.p.). ("Aerial Age Weekly," February 24, 1919.)

Model H, 300 h.p., Hispano-Suiza Engine.

Two diagrammatic cross sectional views of model H illustrate the article describing the differences between this, the most powerful of the series of Hispano-Suiza engines, and the Model I described previously.

The model H is of the water-cooled V-type, with eight cylinders arranged in two blocks of four at an included angle of 90°. The bore is 140 mm. and the stroke 150 mm. The engine weighs, complete with carburettor and magneto, 600 lbs.

The construction of the cylinders consists of an aluminium cylinder block completely lined with separate steel sleeves. The valve seatings are cut into the steel heads of the cylinder sleeves and the valve stems project vertically upward through cast iron guides screwed into bosses in the aluminium. The tappet

arrangement is very ingenious so that the washer beneath each tappet cannot turn on the valve, while if the washer is held the tappet is free to turn. The camshaft is mounted in three bronze bearings bolted to the top of the cylinder block.

The aluminium crankcase is cast in two portions, split at the centre line of the crankshaft. The crankshaft is hollow throughout for lightness and for the passage of oil.

Two magnetos are used firing two sets of plugs simultaneously.

The pistons are aluminium alloy of very simple design with a head $\frac{1}{2}$ in. thick, the side walls tapering from this thickness down to 3/16 in. There are two types of connecting rod, one forked and terminating in two flat feet, and the other split and provided with a cap.

A steel tube cast in the lower half of the crankcase forms the one main oil channel from which oil passes to the four main bearings of the crankshaft. Camshaft and valve lubrication is obtained by leading the oil from a groove around the front end main bearing up through two small steel pipes. To ensure proper lubrication there are three gear pumps, one being a force and the other two suction pumps.

The water pump is a simple centrifugal one which delivers through two pipes to the lower outside rear corners of the cylinder blocks and thence to the radiator.

The carburettor is a Stromberg, specially designed for this engine.

The Model H was used in a Bristol biplane by Capt. Schroeder when making the world's altitude record of 28,900 feet on September 18, 1918. The Loening monoplane, fitted with this model, has developed 145 m.p.h. with full military two-seater load, and has climbed to 25,000 feet. ("Aviation," February 1, 1919.)

Miller 125 h.p. Aircraft Engine.

A short note gives a few general details and two illustrations of this engine, which is of the vertical type, having four cylinders of 4 in. bore and 7 in. stroke, placed in line. Its power output can be raised from 125 h.p. to 155 h.p. by running the engine up to a speed of 2,900 r.p.m.

The water jackets, crankcase, pistons and cylinder are cast alloyanum, a special alloy developed by the Miller firm, while the cylinders are sleeves cast of vanadium iron, completely machined. The lubrication is on a dry base system.

The height over all is 34 ins. and the width 18¼ ins. The weight complete is 410 lbs. ("Aviation," February 1, 1919.)

Sunstedt-Hannevig Seaplane.

This machine has been designed chiefly for long-distance flying over the sea, and the pontoons, wings, and entire rigging are of extra heavy construction. The pontoons are of special design and are each divided into eight watertight compartments. They are 32 ft. long. Their centres are 16 ft. apart and each weighs 400 lbs., including fittings. Each pontoon has an emergency food locker accessible from the deck. The fuselage is flat-sided and has a curved streamline bottom and hood. The machine carries two pilots and two passengers in a cabin at the front end of the fuselage. Directly behind the cabin, balancing with the centre of pressure, is the main gasoline tank, which has a capacity of 750 gallons, sufficient for 22 hours full-speed flying.

The control system is of the standard type, but all the cables are placed beneath the floor, leaving the control column and rudder bar without any wires in the cabin. Dual control is fitted so that the machine can be operated by either pilot. All engine controls and switches are also operative from both seats. The power is given by two Hall-Scott Model "L-6" h.p. engines, directly connected to two-bladed pusher propellers.

The wings are so constructed that the pontoons, power plant and fuselage can be assembled completely before adding the outer wing sections. The central

sections of the wings are 18 ft. 10 in. long. There are five sections in the upper plane, and three in the lower. The upper wing has a chord of 10 ft. near the junction to the central section, and it narrows to 8 ft. 6 in. at the inside of the aileron cut-out. Of this, 8 ft. is of rigid construction, while the rest forms a very flexible trailing edge, increasing the stability and gliding efficiency. The lower plane is entirely constructed of solid ribs.

The dimensions are as follows:—

Span, upper plane	100 ft. 0 in.
Span, lower plane	71 ft. 6 in.
Wing chord, lower plane	8 ft. 0 in.
Wing chord, upper plane	8 ft. 0 in.
Gap between wings	8 ft. 7 in.
Length of machine over all	50 ft. 6 in.
Height of machine over all	17 ft. 7 in.
Dihedral angle, lower plane	2°
Wing curve	U.S.A. No. 5
Total lifting surface	1,537 sq. ft.
Rudder area	22 sq. ft.
Elevator area	54 sq. ft.
Weight	10,000 lbs.
Speed, estimated, full load	80 m.p.h.
Climbing speed, estimated	3,000 ft. in 10 min.
Horse-power, total	440

("Aerial Age Weekly," February 24, 1919.)

Aeromarine Flying Boat: Sportsman Model.

The hull is constructed of waterproof plywood, which avoids seams and the large amount of riveting required when narrow planking is riveted to battens.

An interesting feature of the hull is the use of frames sawed in one piece from a large sheet of waterproof plywood. The bottom of the boat is constructed of built-up plywood riveted with cloth and marine glue between.

The pilot and passenger sit side by side.

It is proposed to equip the machines with six-cylinder 130 h.p. L type engines with electric starters.

TABLE.

General Characteristics.

Spread, upper wing	48 ft. 4 in.
Spread, lower wing	37 ft. 4 in.
Stagger	10 in.
Chord	75 in.
Gap	78 in.
Dihedral	2 degrees
Areas, upper panel (with ailerons)	304 sq. ft.
Areas, lower panel	200 sq. ft.
Ailerons, each	29 sq. ft.
Elevators	15.29 sq. ft.
Stabiliser	39.5 sq. ft.
Vertical stabiliser fin	15 sq. ft.
Rudder	15 sq. ft.
Skid fin	5.5 sq. ft.
Length over all	25 ft. 6 in.
Weight (light)	1,925 lbs.
Weight (loaded)	2,485 lbs.
Gasoline	35 gals.
Wing float buoyancy	264 lbs.

("Aviation," February 1, 1919.)

Curtiss Model K.6 and K.12 Aero Motors.

The K.6 is a six-cylinder water-cooled engine—cylinders *en bloc*—rated at 150 h.p. at 1,700 r.p.m.; the K.12 is a 12-cylinder V motor, water-cooled, rated at 375 h.p. at 2,250 r.p.m., with a 5 : 3 gear reduction to the propeller shaft.

The crankcase consists of two aluminium alloy castings, the upper half being integral with the cylinder water jackets. This ensures extreme rigidity and an appreciable saving in weight.

The cylinders are rough machined from a hydraulic forging of special steel heat treated and then machined all over, with the cylinder head forged integrally. The top of the cylinder is threaded and screwed into the cylinder head casting. Each assembly of six-cylinder heads is bolted to the crankcase which forms the water jacket around the cylinder sleeves.

It is claimed that the new valve gear used on the K.12 motor is a distinct advance over previous practice. The light cam follower relieves the valves of any side strains due to cam action, and provides means of easy adjustment of clearance. As the camshafts are directly over the valves, all rocker arms, push rods, etc., are done away with and the whole assembly is absolutely oil tight.

There is double ignition from two separate magnetos and a duplex carburettor (K.12 has two). Each tube of the carburettor supplies three cylinders. There are hot water jackets on the manifolds to assist in vaporising the petrol.

Lubrication is provided for by an adjustable pressure feed of oil, while a separate return pump with double intake prevents accumulation of oil in either end of the pan, and consequent flooding of the cylinders when the machine is climbing or gliding. ("Aerial Age Weekly," February 3, 1919.)

King-Bugatti Aviation Engine.

The King-Bugatti aviation engine is the American development of the French Bugatti engine, which, when it was decided to put it into manufacture in the United States, aroused very great interest—second only to that evidenced in the Liberty engine. The Bugatti was of the geared type possessing certain features not embodied in the Liberty, and with the special feature of being able to mount a 37 millimetre gun firing through the propeller shaft.

The U.S. Government put the re-designing of the French Bugatti engine for production purposes in the hands of C. B. King, A.M.E. Owing to the fact that the French engine sent over to the U.S.A. had only had a limited test in Paris of 37 hours and had not been in flight, all the points in the design were very carefully considered, both from the performance and production points of view. It was soon discovered that from both these standpoints numerous changes would have to be made.

Upon the completion of the re-designed engine Mr. King sent in a report on the performance of the engine and described in detail the numerous departures from the French design and their effects. The tests thoroughly demonstrated the reliability of the engine and endorsed all the changes which were made.

The article, which is based on Mr. King's report, gives a comprehensive description of the engine, and shows, with the aid of many drawings, the points of difference between the French and American designs.

General Particulars.

Number and arrangement of cylinders	16 vertical, 2 rows of 8 in blocks of 4
Bore	4.33 in. 110 mm.
Stroke	6.3 in. 160 mm.
Compression ratio	5 : 1
Normal brake h.p.	410 at 2,000 r.p.m.
Type of valve gear	Overhead camshaft and valve rockers
Number of carburettors	Four Miller special
Ratio propeller to crankshaft speed ...	.666 : 1

("Aerial Age Weekly," February 10 and 17, 1919.)

Douglas Automatic Aeroplane Ignition Interrupter.

This instrument was developed by Theodore Douglas, President of the Duplex Engine Co., of Brooklyn, New York, under the auspices of the National Advisory Committee for Aeronautics. The function of the instrument is to interrupt automatically the engine ignition, thereby stopping the engine, in the event of the airscrew breaking or other similar breakage resulting in a seriously unbalanced condition of the power plant.

Under war conditions such breakages are very frequent and a large percentage of cases end fatally for the pilot. One of the dangers is the intense vibration resulting from the breakage, which may possibly cause a breakage in a petrol pipe with ensuing risk of fire. Sometimes the most perfect mental and physical co-ordination on the part of the pilot fail to prevent this, a fact which may be better realised to be true when it is remembered that the time interval per revolution varies from roughly one twenty-third to one twenty-seventh of a second.

The interrupter is thought to be particularly desirable on twin engine machines where it may be so installed as instantly to cut out both engines.

In the equipment, too, of " blimps " the instrument would find another important application, as it would tend to reduce the fire risk following airscrew breakages since the airscrew fragments are apt to puncture the gas bag.

As for the instrument itself, it is quite simple and weighs not more than ten ounces. Essentially it consists of a vertical pendulum pivoted so as to swing under the influence of transverse vibrations of the engine and controlled by springs in such a way that only the most intense oscillating shock causes sufficient swing of the pendulum to work the ignition breaking mechanism. The details of the instrument are explained with the aid of photographs.

Two general types of interrupters are made; " maker " instruments, in which there is no flow of current through the instrument except at the moment of interrupting the ignition; and " breaker " instruments, intended for Liberty engines, using the Delco system, where the flow of current is normally constant through the instrument.

Results of tests made by the Navy Department are given, from which it is seen that the instrument possesses all the advantages claimed for it without attendant disadvantages of any consequence. (" Aerial Age Weekly," February 17, 1919.)

Altitude Adjustment for Aircraft Engines.

It has long been recognised that the efficiency of an aeroplane engine varies to a certain extent with variations in atmospheric pressure, and various devices have been patented to compensate for this. The present article describes and illustrates a few barometric regulators, and also a mechanical control in which the air to the carburettor of the engine is compressed in a chamber by a pump driven by the engine itself. The various devices described are illustrated. (" Der Motorwagen," February 28, 1919.)

Instruments for Cross-Country Flying.

The article gives a very brief account of the use of the U.S. Navy Standard No. 1 Aircraft Compass, of which quantities are now available. The compass must be mounted so that it is free from violent vibration, and it must be carefully compensated; moreover, the compensation must be frequently checked, since the magnetism of the metal parts of the machine is continually changing. When the compensation is as accurate as possible, a chart of errors should be drawn up and placed beside the compass. A machine has flown from Akron, Ohio, to Washington, D.C., entirely by compass with a final error of only 8 miles.

Other instruments which are necessary are enumerated, including a turn indicator and an automatic rudder control, and the author suggests that the American Air Mail Service has not sufficiently appreciated the need for such instruments. (" Aerial Age Weekly," February 3, 1919.)

Bijur Electric Starter for Aero Engines.

This has been designed at the request of the Airplane Engineering Department of the Signal Corps, to fit on the propeller end of the crank casing of the Liberty and other engines without the use of intermediate brackets and without making necessary any alteration of the engine. It is built by the Bijur Motor Appliance Company for special use on seaplanes, and consists of a small electric motor 4 ins. diameter, of special design, fitted with double gear reduction and a special form of the Bijur automatic pinion shifting mechanism.

A gear ring is held by the propeller bolts inside the hub flange, and the depression of the starting switch causes the pinion of the starting motor to mesh with the teeth of the gear ring and so cranks the engine. The starting of the engine under its own power automatically de-meshes the pinion. It is not possible to mesh the pinion with the gear ring by depressing the switch whilst the engine is running.

General Particulars.

Weight of starting motor ...	20.5 lbs.
Weight of gear ring	3.6 lbs.
Normal starting current ...	100 amperes (12-volt battery)
Cranking current	90-150 amperes
Maximum torque available on engine crankshaft	1,300 lbs. ft.
Normal cranking speed... ...	40 to 50 r.p.m.
Weight of 6-cell storage battery rated at 24 ampere hours ...	25 to 35 lbs.

Both articles are illustrated, and show the method of mounting. ("Aviation," February 1, and "Aerial Age Weekly," February 10, 1919.)

Miessner Airfone.

This is a device for the intercommunication between pilot and student or pilot and observer. It is claimed that its use would halve the time taken for training cadets, and the claim is supported by the evidence of army officers.

The airfone is entirely an acoustic instrument, it being a speaking tube designed for use on an aeroplane in full power flight. Electric telephones on the microphone principle do not give such satisfactory results. Not only has the airfone been tested under flying conditions on training planes, but it has given entire satisfaction on planes mounting 400 h.p. Liberty motors while in flight and making loops, nose-dives, tail-spins, etc. Moreover, no difficulty was experienced in making a conversation by talking into the transmitters placed only two feet from the exhausts of a 12-cylinder Liberty motor mounted on a test stand and in the full propeller slipstream.

The airfone has been designed after a close and detailed study of aircraft noise conditions. It consists essentially of a flexible speaking tube provided with a mouthpiece and a neck band, and a helmet to which two earpieces are attached, suitable communications between speaking tube and earpieces being provided. In practice the instrument has been found to fulfil the requisite conditions that:—

(1) The aeroplane noises are prevented from reaching the ears directly through or around the earpieces;

(2) The highest ratio of intensity of voice sounds to aeroplane noises reaching the ears is obtained; and the acoustic characteristics are such as to permit of good articulation.

The earpieces consist of pneumatic cushions or rings which surround the ear and maintain an airtight contact with the head with but small pressure.

There is a certain optimum tube diameter, and the tube length must not be equal to $\frac{1}{4}$, $\frac{3}{4}$, $\frac{5}{4}$, etc., of the wave length of the motor and exhaust sounds.

A combination radio and airfone apparatus has been designed for use on aircraft equipped with radio reception apparatus. The wireless and airfone communications may be received separately or together as desired by the wireless operator. ("Aerial Age Weekly," February 10, 1919.)

Aircraft Instruments for Blind Flying.

The article deals with instruments to enable a pilot to maintain his proper attitude when flying in clouds, fog, or darkness.

Longitudinally the airspeed indicator, used in conjunction with the tachometer, indicates the correct attitude. Laterally the banking indicator and lateral clinometer serve to show only divergence from a stable lateral position, and the compass will only indicate accurately when the machine is flying on a straight course. A turn indicator is then described which would show instantly and accurately any divergence from a straight course or from a lateral horizontal position.

The mechanism is simple. A small gyro is driven on a lateral axis at a speed of about 5,000 r.p.m. by suction obtained from a Venturi tube. The frame holding the gyro bearings is hung on a fore and aft axis, but its rotation about this axis is restrained by light centralising springs. When the machine starts to turn about a vertical axis the gyro precesses, and this precession, many times greater than the turning motion of the aeroplane, is indicated on the dial of the instrument. Thus, if the machine can be kept on a straight course the compass can be used to indicate the direction. The turn indicator described weighs 1.75 lbs. ("Aviation," February 1, 1919.)

Value of Plywood in Aeroplane Fuselage Construction.

Lieut. Stefano d'Amica, of the Italian Aviation Mission, in this article states that the wired truss form of fuselage is giving way to the plywood covered fuselage, and that in its most common form the fuselage is made of four longerons tied together by means of diaphragms and then covered by plywood. The shearing stresses are taken care of by stiffening the outside covering with ribs of wood.

The abandoning of the truss construction was desirable during the war because of the ever-increasing scarcity of metal fittings as well as on account of the excessive cost and the shortage of labour. The result has been that, although the fuselage has forfeited a little the advantage in weight, the machine has gained in life and efficiency.

Up to the present the increase of weight due to plywood construction has precluded its use in large machines. It may be foreseen, however, that in the very near future this disadvantage will be overcome.

Taking the case of the ordinary tapering fuselage of rectangular section, the method of making stress calculations is given, assuming the maximum loading as occurring when the machine is landing, and the force at the tail skid at that time as twice the static load, when the machine is resting on the ground. Combined with the moment at any section due to this load, is that due to the weight of the overhanging part of the fuselage, and to the wind force on the fin and rudder. No mention is made of the large downward force on the tail which comes into action during a steep dive and especially on beginning to flatten out; also, the inclusion of the rudder force with the other forces on landing hardly appears to be logical.

Tests have been made which show that in making the strength calculations the sectional area of the longerons may be considered as increased by an amount equal to 20 times the thickness of the plywood to allow for the additional strength due to the plywood.

In calculating the shearing stresses, it may be considered that one half of the reaction will be taken care of by the plywood acting in tension and the other half by the diagonal bracing, at the sides, which stiffens the structure.

Recently tests have been conducted on fuselages made of wood, in which the longitudinal longerons running the full length of the fuselage have been eliminated as well as the stiffening ribs. These tests have already given good results and it seems as though they will lead to a practical result which would bring a great advantage in weight. ("Aerial Age Weekly," February 17, 1919.)

Selecting Aerofoil Sections for Speed Range.

Two charts are given which serve as a rough and ready means of choosing the best aerofoil for speed range, and incidentally of estimating approximately the performance of a given machine. They are not claimed to be strictly accurate, but are, however, based on a study of current practice in the tests of numerous machines.

The first diagram consists of curves giving the low speed at sea level plotted against surface loading for a number of U.S.A. aerofoils and R.A.F.15.

On the second chart three sets of curves are plotted:—

(*a*) Speed range as a percentage of low speed plotted against h.p. weight in lbs.

(*b*) Air speed required for sustentation (percentage of minimum speed) plotted against percentage of lift coefficient.

(*c*) L/D plotted against percentage of maximum lift coefficient for the same aerofoils.

All curves have been corrected for scale effect, 17 per cent. stagger, gap chord 1.06, aspect ratio 7 and rounded wing tips. Angles of incidence are also indicated.

It has been assumed that the machine is a good single engine biplane tractor with full equipment, and air density, h.p., etc., are taken at sea level.

The charts are exceedingly simple to use. Suppose an engine given, and the total weight of machine and total area of main planes. To find the aerofoil that will give the best speed range, proceed as follows:—By means of (*a*) find the point corresponding to the given wing loading and h.p./weight. This gives on curve (*b*) the air speed for sustentation, and the best value of L/D found on curve (*c*) for the value of lift coefficient corresponding with this air speed gives the aerofoil that will give the maximum speed range. The low speed at sea level can be found from chart I. and hence minimum and maximum speeds are known.

Several examples are worked out and a method of estimating the permissible limit for parasitic resistance is given. ("Aviation," February 1, 1919.)

Air Transport Company for Vienna.

A company has just been floated in Vienna for postal, passenger and goods transit by air. The concern bears the title of "Luftverkehrsstadien-Gesellschaft m.b.H." (Aerial Transport Promotion Co., Ltd.). The objects of the company, as set forth in the Vienna Commercial Register, are: To organise aerial transport of all kinds, especially the conveyance of mail, passengers and goods by air, and all business and undertakings connected therewith; also the conduct of negotiations with the Government, public bodies and third parties, the conclusion of agreements with them and the transfer of such agreements to the Aerial Transport Company to be founded in conjunction with the present company. The share capital is to be Kr.300,000, of which Kr.90,000 have been paid up.

This announcement is somewhat surprising in view of the failure hitherto of aerial traffic in Austria. But the objects of the present undertaking should not be compared with previous organisations, which are said to have been most unsatisfactory. The present company's intention is just to study ways and means to the desired end. It is hoped that German undertakings will also be stimulated by the step now taken in Austria. The Schutte-Lanz Co. have already established an "Aerial Navigation Bureau," although its operations seem to be confined at present to the hiring out of aircraft. ("Der Motorwagen," February 28, 1919.)

Cost of Aeroplane Operation.

The total costs of operation of the army aeroplanes which took part in the pioneer flight from San Diego to Washington are estimated at $8,827.5, or an average of $2 a mile for four aeroplanes and eight men. Comparison with the

results given out by the Post Office, which does not include depreciation but does add salaries, shows that Ct.50 a mile for a two-seater is a general figure that can be used with safety.

The four coast-to-coast aeroplanes cost $12,000 each, a total of $48,000. Between San Diego and New York City four propellers had to be replaced, and there were other repairs which came to an estimated total of $1,500. Each aeroplane consumed 15 gallons of gasolene an hour, or a total of 3,300 gallons. This fuel cost an average of nearly Ct.50 a gallon, or a total of $1,645. One-half gallon of oil was consumed each hour, a total of 110 gallons, costing $82.50. It is estimated that each engine depreciated in value one-fifth, and each aeroplane less than one-tenth. Thus the depreciation on engines may be estimated at $480, and on the aeroplane at $4,000. ("Air Service Journal," February 8, 1919.)

Chicago-New York Airship Line.

It is announced by the Manufacturers' Aircraft Association that one of its members is investigating the feasibility of establishing a passenger service between New York and Chicago by means of rigid airships of medium size.

The airships proposed for this service are to have accommodation for twenty-five passengers in addition to a crew of ten, and to develop a speed of 70 m.p.h., which should enable the trip from New York to Chicago to be made in less than twelve hours, or fully 50 per cent. less than the time required with existing rail facilities.

The fare contemplated is $520, an amount which, although it may be warranted by the great initial outlay, would hardly tend to popularise commercial aeronautics. In order to reduce fares and thus make aerial transit popular, a State subsidy is advocated, until such time as aerial services can pay their way without at the same time charging very high fares. ("Air Service Journal," February 8, 1919.)

Organisation of Aerial Ports.

This article has been taken from "Rivista dei Transporti Aerei." Many suggestions are put forward for the arrangements of aerial ports. They should be situated in pleasant, sheltered places, with extensive arrival and departure areas, distinctly marked so as to be visible from a great distance. Tracks must also be made close to hangars, offices, etc., for use in loading and bringing in supplies, etc. Signals are discussed for landing both by day and night. With regard to the latter, care must be taken that the signal must not be a stumbling block—it ought to be a point to be touched and not avoided. One method of doing this is described whereby lamps are placed in cavities in the ground and covered over with strong glass plate flush with the ground. The lights can be controlled from a central post.

Remarks are made as to towing the machines, fuel accommodation, and the arrangement of the hangars according to the functions of the machines housed in them, and strict management of the port exactly as in the case of a sea or river port is advocated. ("Aviation," February 1, 1919.)

New York Police Volunteer Aero Squadron.

Plans to organise an aero squadron to be part of the New York Police Department have been made public. The project has been well received and will no doubt be carried through. The aero squadron of the U.S.A. provides twenty officers, including the executive, technical, medical, etc., and twelve pilots; also 154 N.C.O.s and men. It is proposed that the Police Aero Squadron shall always conform to the requirements of the U.S. Army. It is suggested that other progressive cities should form police aviation units, the smaller cities organising aero companies of which three make up a squadron. These units so organised would be of potential military value. ("Aerial Age Weekly," February 3, 1919.)

Activities of the Bureau of Standards.

For the work of the Bureau of Standards during the fiscal year, 1919-20, estimates for appropriations have been submitted amounting to the value of $2,098,760. The activities of the Bureau will be considerably extended, and will include the erection of a building for an airplane engine research laboratory, housing four dynamometers, a refrigeration plant, two altitude laboratories, and the necessary equipment for running altitude tests of airplane engines corresponding to heights up to 40,000 feet.

A unique feature of the airplane research programme is the development of a system of free flight tests made in normal flying as actually practised by army aviators, and several special autographic instruments are being developed for use in this connection.

The Bureau's aeronautical instrument laboratory will devote special attention to such instruments, of which three kinds have already been designed, in addition to investigations on other instruments for aerial navigation, etc. ("Air Service Journal," February 1, 1919.)

Exhibits of the Curtiss Aeroplane and Motor Corporation.

This article describes the different models the Curtiss Engineering Corporation exhibited at the Aeronautical Exposition. Illustrations are given of Model H.A. Hydro-Aeroplane, M.F. flying boat and 18-B biplane.

Curtiss Model M.F. Fying Boat.

This is a development of the well-known "F" type, being one of the smallest made by the Curtiss Company. The maximum and minimum speeds are 69 and 45 m.p.h., and rate of climb 5,000 ft. in 27 min. The machine is of the "pusher" type, fitted with 100 h.p. Curtiss OXX 8-cylinder "V" motor which will give a range of 325 miles at economic speed with two passengers.

The wing span is 49 ft. $9\frac{3}{8}$ in., length 28 ft. $10\frac{3}{16}$ in., height 11 ft. $9\frac{3}{8}$ in., weight 1,796 lbs. empty, and will carry a load of 636 lbs. One of its chief features is ease of manipulation.

Curtiss Model 18-B Biplane.

A development of the combat type of machine designed for the U.S. Navy, and is the same machine that, equipped with triplane wings, secured the world's speed record.

The body is elliptical in section and well streamlined, the machine being built for speed and equipped with a 400 h.p. Curtiss K-12 motor, which is said to be lighter than any other 400 h.p. motor.

The length is 23 ft. $3\frac{3}{16}$ in., and height 9 ft. $10\frac{3}{8}$ in. It weighs 1,825 lbs., and will carry 1,076 lbs.

Curtiss Model J.N.-4D-2 Biplane.

A tractor machine used for training, for which purpose it has dual control and carries two passengers "tandem."

The power unit is an 8-cylinder "V" type 90 h.p. Curtiss OX5, having an economical consumption of $\frac{1}{2}$ lb. of petrol per h.p. hour.

Below are given the principal particulars:—

Horizontal speed	75 m.p.h.
Minimum speed	43 m.p.h.
Rate of climb	5,000 ft. in 10 min.
Wing span (upper)	43 ft. $7\frac{3}{8}$ in.
,, ,, (lower)	33 ft. $11\frac{1}{4}$ in.
Wing chord	$59\frac{1}{2}$ in.
Length over all	27 ft. 4 in.
Height	9 ft. $10\frac{5}{8}$ in.
Weight	1,580 lbs.
Useful load	550 lbs.
Range	250 miles

Curtiss Model H.A. Hydro-Aeroplane.

The machine is designed for speed and has great weight-carrying capacity, the useful load being 1,012 lbs. and weight, empty, 2,638 lbs. Both wing spans are 36 ft. and 72 in. chord. It is equipped with two Liberty 12 motors, is capable of a maximum speed of 130 m.p.h., a minimum of 62 m.p.h., and will climb 8,500 ft. in ten minutes.

Curtiss Model H-16-A Flying Boat.

The H-16-A is a twin-engined machine designed to carry 11 passengers. Its total carrying capacity is 3,000 lbs., over 1,000 of which may be left free for passengers exclusive of crew. It will travel at 95 m.p.h., and has a range of 675 miles.

Curtiss K-6 and K-12.

These engines are of the "V" type, water-cooled and remarkably light construction. The K-12 weighs 700 lbs. nett, giving a dead weight per rated horse-power of 1.86 lbs. The consumptions of petrol and oil are 0.55 lbs. and 0.03 lbs. respectively. It has forced lubrication and dual ignition. Some principal dimensions are given below:—

Bore	$4\frac{1}{2}$ in.
Stroke	6 in.
Over all length	$68^{5}/_{16}$ in.
,, width	$27\frac{7}{8}$ in.
,, depth	$40\frac{1}{8}$ in.
Width at bed	$15\frac{3}{4}$ in.
Height from bed	$24^{3}/_{16}$ in.
Depth from bed	$15^{15}/_{16}$ in.

Curtiss OX-5.

An 8-cylinder "V" type engine developing 90 h.p. at 1,400 r.p.m. Bore 4 in. and stroke 5 in.; fitted with two magnetos and forced lubrication. Nett weight 375 lbs. and weight per rated h.p. 4.17 lbs. Consumption 0.60 lb. of petrol and 0.03 lb. of oil per b.h.p. hour. Dimensions over all $68^{5}/_{16}$ in. long, $27\frac{7}{8}$ in. wide, $40\frac{1}{8}$ in. deep. Width at bed $15\frac{3}{4}$ in., height from bed $24^{3}/_{16}$ in., depth $15^{5}/_{16}$ in. ("Air Service Journal," March 8, 1919.)

ABRIDGMENTS OF RECENT PATENT SPECIFICATIONS (AERONAUTICS).

122,913. W. C. Hume, Victoria Works, St. Lawrence Road, Newcastle-on-Tyne. February 8, 1918.

Cramps; Vices.—A cramp or vice particularly for use in the manufacture of ribs or other parts of aircraft, comprises an inner former and outer movable jaws operable by levers to clamp the rib, etc., against the former. In one form the work is gripped between a fixed inner former secured to the base and movable jaws which are operated by levers pivoted to the base and tenoned into the jaws and connected thereto by screws. A foot-piece arranged below the former is preferably provided to raise the work so that webs or other parts may be secured thereto and the jaws are provided with recesses to clear the foot-piece. Links may connect the levers for simultaneous operation and the jaws may be in sections, each provided with one or more operating levers. In a modification, the levers are arranged beneath the base and are connected to the jaws by pins extending up through slots in the base.

122,916. G. Hodges, 40, Dowling Street, Dunedin, New Zealand. February 9, 1918.

Planes, Construction of; Propelling.—With a view to increasing the lift of flying machines, a subsidiary plane hinged at its front edge to the main plane is moved up and down so as to collapse and extend the chamber formed between the two planes, an inlet valve being provided in the upper plane and an outlet valve in the lower plane. The drawings show a main plane having an upper plane hinged and connected to the main plane at the side and rear edges by fabrics, inlet and outlet valves being provided. The upper plane is driven by crank and connecting rod from the engine, or from wind-driven propellers, which may also be coupled to the engine by chain gear and a clutch. A crank mechanism of variable stroke is shown, the crank and connecting rod being arranged to drive the upper plane through a slotted link pivoted, and a rod connected to the plane and to a block which may be slid along the link. In modification, the moving plane may be below the fixed plane, or a moving plane may be arranged between two fixed planes or a fixed plane between two movable ones.

Aerostats.—An exhaust pipe from the engine may be arranged along the front edge of the plane with orifices opening upwards, so that the heated gases are drawn into the chamber formed between the planes. This chamber between the planes may be partitioned.

122,948. A. Collis, Revelstoke, Somerton Road, Cricklewood, London. March 6, 1918.

Clinometers.—A universal electrically acting clinometer for aircraft comprises a mercury container connected to one pole of a source of electricity, and a series of insulated contacts arranged in the form of a fore-and-aft cross connected to the other pole. These contacts project through an insulating plate so that one or more of them, by contact with the mercury, completes a circuit or circuits and thus illuminates a lamp or lamps. The lamps are arranged cruciformly, one to each contact, and alternatively other visible or audible signals may be employed. When the aircraft is upside down all the lamps are illuminated.

122,949. E. Meldal, Coast Artillery School, Golden Hill, Isle of Wight. March 6, 1918.

Levels.—Two similar closed circular chambers filled with liquid and each containing a pivoted pendulum are hinged together and provided with means by which one can be set in a plane at right angles to that of the other. In use on aircraft, in this working position, one pendulum indicates fore-and-aft inclination and the other sideway inclination. Each chamber is shallow in comparison with its diameter and has one face transparent. The pendulum is pivoted at the centre of each chamber and carries an arm extending diametrically through the pivotal point. The chamber indicating fore-and-aft inclination is mounted in its plate so as to be rotatable on its centre in order to compensate for deflection of the pendulum from the vertical due to the speed of the aeroplane. The rotation may be made by an arm provided with a pointer moving over an arc, graduated to indicate the speed in miles per hour.

122,974. A. G. France, 64, Chancery Lane, London. April 25, 1918.

Wire-Strainers.—Relates to rigging screws for aircraft, etc., of the type in which the eyebolts to which the wires are attached screw into an internally-threaded sleeve, and consists in locking such devices by providing an external screw-thread upon and splitting the sleeve adjacent to its ends, a nut sliding loosely over the eyebolt being adapted to screw on to each end of the sleeve. The drawings show the tubular sleeve or body with right and left-hand eyebolts, the tommy for tightening being inserted in holes in an enlarged part at the centre of the sleeve. Externally at each end the sleeve is coned slightly, provided with a screw-thread and slits formed at one or more points, and nuts are screwed over the ends. In modifications the nuts have a part of lesser diameter screwed to engage the eyebolt thread, and may be slightly tapered internally to ensure binding, or the screwed end of the body may instead be tapered or both parts tapered.

122,996. Phœnix Dynamo Manufacturing Co. and W. O. Manning, Thornbury Works, Bradford. July 17, 1918.

Controlling Motive Power, Gear for.—The throttle or other controls of twin-engined aircraft and naval vessels are connected to a single lever in such a manner that movements of the lever in one plane operate both controls in the same direction and movements in a plane at right angles operate the controls in opposite directions. The drawings show a lever pivoted about a longitudinal pin carried by a frame pivoted on a shaft on which are loosely mounted two pulleys or pairs of pulleys connected by cables to the respective engine controls. Crankpins on the pulleys are connected by links, having universal joints to lateral extensions on the lever. Where pairs of pulleys are used, one pulley of each pair is connected to a second control device to permit of dual control.

123,051. G. Debenedetti, 44, Corso Vittorio Emanuele, Turin, Italy. September 3, 1918. Convention date, February 6. Not yet accepted. Abridged as open to inspection under Sect. 91 of the Act.

Metal Tubes.—Metal tubes made from one or more strips of metal with the edges welded or soldered to form a longitudinal joint, particularly tubes, of elongated cross-section for use in aeroplane, etc., framework, are strengthened transversely by internal ribs, webs, or corrugations. The tube may be made from two strips and assembled on opposite sides of a web. The web may be omitted, the inturned edges of the strips forming the strengthening ribs. In another form a single strip is used, part forming the transverse web and the remainder being bent round to form the outer wall of the tube. In a further modification, made from a single strip, the inturned edges form a rib at one side and the other side

is formed with a corrugation of any desired cross-section. The corrugation and rib may meet within the tube and may be there welded together to form a transverse web. In other modifications the tube is formed with two opposed corrugations.

123,052. G. Debenedetti, 44, Corso Vittorio Emanuele, Turin, Italy. September 3, 1918. Convention date, February 8. Addition to 122,622. Not yet accepted. Abridged as open to inspection under Sect. 91 of the Act.

Metal Tubes.—Metal tubes formed as described in the parent Specification from one or more strips of sheet metal with hooked interengaging edges are strengthened transversely by re-entrant corrugation. Modified forms of seam are described, and a tube made from two strips in which adjacent edges, instead of interengaging, are held together by narrow jointing strips.

123,074. Stabilimenti Biak—Ing. A. Pouchain, 12, Corso Stupinigi, Turin, Italy. January 30, 1919. Convention date, February 1, 1918. Not yet accepted. Abridged as open to inspection under Sect. 91 of the Act.

Aeroplane Axles.—An axle for aeroplane undercarriages is of the section shown, the centre of curvature of the outer surfaces of the flanges being at the centre of the section. The axle may be formed by curving the flanges of ordinary I-section bar.

123,085. Soc. des Ateliers d'Aviation L. Breguet, Velizy-Villacoublay, Seine et Oise, France. February 3, 1919. Convention date, February 8, 1918. Not yet accepted. Abridged as open to inspection under Sect. 91 of the Act.

Tanks and the Like, Arrangement of.—In means for quickly releasing the tanks or reservoirs of aircraft the tank is supported by triangulated members passing through the tank and connected to the aircraft framing by bolts. One of these bolts is released by the pilot by means of a Bowden connection, whereupon the tank falls about the remaining bolts, which are then released by the engagement of the tank with a lever connected to the bolts by cords. The ejection of the tank is assisted by elastic ties secured to the framing and detachably connected to the tank. The feed-pipe connection is of glass or other fragile material.

123,130. Grimston Tyres, Ltd., The Camp, St. Albans, and J. F. Cooper, Ivy Cottage, Port Vale, both in Hertfordshire. January 14, 1918.

Vehicle Wheels; Tyre Attachments to Rims.—A rim, particularly for use on landing wheels of aircraft, comprises side channels in the outer portions of which the edges of the tyre are clamped by independent sets of screw devices such as the bolts and nuts or bolts screwing directly into the channel walls. The tyre may be an ordinary outer cover, or a separate air-tube may be dispensed with, for which purpose the walls of the channels may be coated to assist in making airtight joints. The tyre may also be provided with an internal rubber, etc., tongue. The heads of the bolts and the nuts, if used, may be formed spherical portions to engage the rim holes; tee-headed bolts may be used; taper-bolts may be used to exert an outward radial thrust on the tyre edges; or non-removable turnbuckle devices may be employed adjusting the rim channels. The tyre edges may be specially shaped to correspond with the rim formation—*e.g.*, each edge may have a projecting rib engaging a groove in the channel wall.

Wheels with Non-Supporting Casings enclosing Spokes.—Wheels with rim constructions as described above may be wind-shields comprising an annulus having its outer edge secured, as by stitching, to the tyre, or to a support extending from the rim, the inner edge being secured to a ring to which the main disc casing is attached. The ring may be connected to the wheel by rim-adjusting screws.

123,174. Dunlop Rubber Co. and W. H. Paull, Para Mills, Aston Cross, Birmingham. February 18, 1918.

Shock of Landing, Deadening; Land Wheels.—An undercarriage for aircraft has three or more small wheels of large cross-section arranged one behind another on a common frame in place of each of the usual large diameter wheels. The drawings show three wheels mounted in a curved frame which is pivoted about the axis of the front wheel, a spring acting on the front end of the frame and normally maintaining two stops in contact. A modification is described in which the frame is pivoted about the axle of the central wheel where an additional spring is provided. In another modification the wheels are mounted on a rigid frame. The wheels may have pneumatic tyres of large cross-section or they may be inflated discs, and the frame may have a streamline shield or casing to enclose the wheels.

123,196. G. H. Thomas, 27, Buckingham Gate, and E. J. Edgar, 16, Teignmouth Road, Brondesbury, both in London. March 8, 1918.

Vehicle Wheels.—Wind shields for aeroplane and other vehicle wheels are formed with elastic peripheries capable of preliminary deformation circumferentially, either by contraction or distension, so as to be adapted to be sprung into and out of engagement with a circumferential seating on the wheel rim. The elastic periphery may be formed of a split ring of spring metal or of an endless spring; the circumferential seating may be continuous or formed of a series of lateral extensions; and the wind shield may be formed with a peripheral gap.

123,278. W. R. D. Shaw, 32, Charing Cross, London. August 22, 1918.

Planes, Arrangement of.—Aeroplanes are provided with a plurality of positively staggered main planes of which those below the centre of gravity are set at a smaller angle of incidence than the upper planes and have a lateral dihedral angle, the upper planes having no dihedral angle. The aeroplane shown comprises lower planes arranged at the dihedral angle and at a smaller angle of incidence than the upper planes. The stabilising action of the lateral dihedral angle becomes more effective as the speed of the machine is reduced, since the lower plane takes a larger proportion of the lift when the incidence of the planes is increased by altering the attitude of the machine. Further, by reason of the staggered arrangement of the planes and their difference of incidence a longitudinal stabilising action is obtained. The maximum lift coefficient is practically constant over a range of altitudes, thus producing an anti-stalling effect as well as an efficient landing air brake.

123,374. S. E. Saunders, White House, East Cowes, Isle of Wight. February 16, 1918.

Spars.—Hollow wooden struts and spars, particularly for aircraft, are built up of longitudinal sections secured together at their edges and have transverse fins in conjunction with the joints meeting at the centre of the section. The drawings show a cross-section of a circular spar composed of four sections with strengthening ribs and cross-fins, a strip of veneer or linen being wound on the outside. Blocks completely filling the section are fitted at intervals. The sections may be thickened at their meeting edges, instead of or in addition to ribs being formed, and fitted with dowels or with longitudinal keys. Square section spars also are described.

123,422. S. W. Cole and C. Hannaford, of Burney & Blackburne, Tongham, Surrey. March 6, 1918.

Signals.—A pneumatically-operated order telegraph for use on ships, aeroplanes, etc., comprises flexible air chambers at the transmitting and receiving stations respectively arranged in casings fitted with indicating dials over which

move pointers. One of these pointers is attached to a screwed shaft operable by a nut, and on turning this nut movement is imparted to one of the chambers through lever and link mechanism. Variations in pressure in this chamber are transmitted by a pipe to the other chamber, and movements of this chamber are transmitted to one of the pointers by means of a lever and chain passing over a drum on the spring-controlled shaft of this pointer. When the other pointer is at zero position it is held by a spring catch engaging a recess in the top of casing, and in this position a valve connects the pipe to atmosphere. A call signal consisting of a buzzer, or a glow lamp, may be used in connection with the device.

123,465. W. B. Crofton, 56, Harley Street, Yeoville, Johannesburg, South Africa. May 23, 1918.

Internal Combustion Engines; Four-Stroke Cycle Engines; Pumps; Cylinders, Attachments to, for Supplying Gas.—In order to obtain increased power in aircraft or other engines, or to enable low-grade fuel to be used, the explosion in each cylinder acts on the free piston of a compressor, which supplies fuel gas to the next firing cylinder at the beginning of the compression stroke in the latter. In the form shown a pump cylinder is screwed into the cylinder head and draws gas from the induction pipe or other source through a conduit and expels it through another conduit leading to the next firing cylinder, the conduits being provided with non-return valves. The pump piston is of two diameters, the head being actuated by the engine explosion acting against a spring and the space beneath the enlarged part has a cock for admitting sufficient air to cushion the piston. The cocks on the several pumps may be simultaneously actuated. The supply of gas to the pumps may be controlled by a throttle valve on the first-mentioned conduit; in the case of an aircraft engine this throttle valve is gradually opened at increasing altitudes.

123,466. W. G. Wise, Station Road, Winslow, Buckinghamshire. May 24, 1918.

Inclinometers for Aircraft, etc.—Relates to apparatus showing fore and aft and lateral inclination, more especially for aircraft, and consists mainly in the arrangement of a pendulum within a weighted casing for the measurement of one set of movements and of a pivoted mounting for the casing to enable it to indicate movements of the other kind. The casing consists of two parallel metal plates, a short distance apart, connected at the peripheries by pillars. Upon a central spindle is secured a pendulum member, and also gear wheels, engaging left and right gear wheels, and respectively mounted in brackets. Index hands are secured to both ends of each spindle, and indicate upon the graduated circles. The casing is provided with a heavy weight at its lower end, and with its contained parts is freely suspended by means of trunnion pins from end plates of the main frame, the trunnion pins carrying index hands moving over graduated dials, of which the reflections are observed in pivoted mirrors that are adjustable in quadrant extensions of the main frame. A glass cylinder or rounded cover is fitted to the main frame.

H. T. P. Gee,
25, Victoria Street, Westminster, S.W.1, and
70, George Street, Croydon.

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Multiple-Engined Aeroplanes. ("The Engineer," March 28, 1919.)

Oxygen and the Transatlantic Flight. Major T. S. Rippon. Diagrams. ("Flight," March 27, 1919.)

The Future of Commercial Aeronautics. G. Holt Thomas. ("Modern Transport," March 29, 1919.)

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American Aero Engines. An outline description with photograph of each of the following engines is given:—The 400-h.p. Liberty "Twelve"; the King-Bugatti; the Curtiss K-6 and K-12; the Wright-Martin Hispano Suiza; the Duesenberg Model H; the Lawrence 60-h.p. air-cooled; the Union six-cylinder water-cooled (120-h.p.); the 300-h.p. Knox Twelve; the 450-h.p. 12-cylinder A-8 Hall-Scott; and the 80-h.p. Le Rhone by the Union Switch & Signal Co., Pennsylvania. There is also given a very useful tabular statement of the principal features of 36 Allied and enemy aero engines in general use. ("Aerial Age Weekly," March 3, 1919.)

American Aeroplanes and Seaplanes, 1918-19. This is a photographic survey of American-built aeroplanes and seaplanes of recent construction. ("Aerial Age Weekly," March 3, 1919.)

The Napier "Lion" Aero Engine. In this article a fairly detailed description, with photographs and two small drawings, is given of the Napier 450-h.p. "Lion." ("Aerial Age Weekly," March 3, 1919.)

German Aeroplanes. Some of the newer types. ("Times Engineering Supplement," April, 1919.)

From Large Aeroplanes to Super-Aeroplanes. This article gives particulars and illustrations of recent types of large bombing planes, including the Staaken, manufactured by the Zeppelin Works. ("Der Motorwagen," March 10, 1919.)

A Theoretical Investigation into the Stresses Arising in the Landing Gear of an Aeroplane. H. H. Thomas. ("Flight," April 10, 1919.)

The Development of Air Construction. C. T. R. Campbell. Paper read before the Institute of Naval Architects, April 10, 1919. ("Engineering," April 11, 1919.)

Rigid Airship Design: The Tension in the Diagonal Bracing Wires. E. H. Lewitt. Illus. ("Aeronautics," April 17, 1919.)

Wirelessly-Directed Aircraft. ("The Engineer," April 11, 1919.)

A New Aero-Camera. Illus. ("Aeronautics," April 10, 1919.)

Commercial Transportation and High-Speed Services by Air. G. Holt Thomas. Reproduced from "Ways and Means," April 12, 1919. ("Aeronautics," April 17, 1919.)

The Loads and Stresses on Aeroplanes. J. Case. Serial. Diagrams. ("Aeronautics," May 1, 1919.)

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Fiat Co.'s New Aero-Engine. Illus. ("Aeronautics," April 24, 1919.)

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The Cooling of Aero-Engines. Methods by which designers have overcome difficult problems. Illus. ("The Autocar," April 26, 1919.)

Douglas Automatic Aeroplane Ignition Interrupter. Illus. ("Aviation," March 1, 1919.)

System of Testing Fuel Jets in Zenith Carburettors. All Zenith jets are tested in a special machine (illustrated), designed to measure accurately the quantity of water which will flow through the jet in one minute, the head of water which will flow through the jet in one minute, the head of water above the jet being maintained constant. The timing is electrically controlled. The machine will take four jets at once, and it is claimed that four jets can be tested in 1½ minutes, or 160 jets per hour, by one operator. A table shows the rate of flow under one metre head for various jets. ("Aerial Age Weekly," March 24, 1919.)

Some Future Possibilities of Aerofoil Design. W. E. Astin. ("Flight," April 17, 1919.)

Some Useful Fuselage Strut Curves. A. J. Sutton Pippard. Illus. ("Aeronautics," April 24, 1919.)

Dimensions of Steel Tube Struts. Two charts are given from which it is possible to determine the ultimate strength of a mild steel tube of a given length, diameter, and thickness when used as a strut. By dividing by the appropriate factor of safety the permissible load on the strut is obtained. The charts are based on an ultimate strength for the material of 70,000lbs. per square inch. A figure is also given showing the comparative dimensions of tubular and streamline struts of equal strength. E. S. Bradfield. ("Aerial Age Weekly," March 24, 1919.)

Route Indicator for Aerial Navigation by Estimation. ("Comptes Rendus," April 7, 1919.)

Air Mileage of Aeroplanes Intended for Long Distances and for Transport. J. Dennis Coales. ("Engineering," May 2, 1919.)

United States Post Office Air Mail Service. A detailed tabular analysis of running and maintenance costs for January, 1919. Twelve aeroplanes were used, and the total distance flown was 11,138 miles. The costs per mile work out as follows:—Overhead charges, $0.4492; flying cost, $0.2785; maintenance, $0.5060; total, $1.2337. ("Aerial Age Weekly," March 24, 1919.)

Drawing Office Data. E. O. Williams. ("Flight," April 17, 1919.)

National Aeroplane Factory, near Manchester. Illus. ("The Engineer," May 2, 1919.)

The Tarrant Triplane. Illus. ("Engineering," May 9, 1919.)

Vickers' Vimy-Rolls Aeroplane. Illus. ("Engineering," May 9, 1919; "The Engineer," May 9, 1919.)

Shop Practice in Respect to Aircraft Steel. Major H. P. Philpot, R.A.F. ("Aeronautical Journal," March, 1919.)

The Loomis Cooling System for Aircraft. Some features new to aeroplane cooling systems and adaptable to any aeroplane carrying a water-cooled engine have been developed at McCook Field, Dayton, Ohio. Particulars are given of the Loomis cooling system, taken from the Bulletin of the U.S. Experimental Department, Aeroplane Engineering Division. ("Aeronautics," May 8, 1919.)

New Designs of Petrol, etc., Cocks for Aircraft. Describes and illustrates designs of uniform "switch" cocks, etc., which were the subject of a competition by the German "National Aviation Prize Fund" last year. The method of testing adopted is also described. ("Zeitschrift des Vereines deutscher Ingenieure," April 12, 1919.)